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THE USE OF MULTIFUNCTION KEYBOARDS IN SINGLE-SEAT AIR FORCE COCKPITS

CREW SYSTEMS INTEGRATION BRANCH
FLIGHT CONTROL DIVISION

APRIL 1977

TECHNICAL REPORT AFFDL-TR-77-9
Final Report for Period 3 July 1974 – 31 December 1975

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John H Kearns III

Signature

Project Engineer/Scientist

FOR THE COMMANDER

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Two types of multifunction keyboards (MFKs), projection switches, and plasma panel were designed to consolidate many of the aircraft controls/displays into a single, easily-reachable control panel. Pilot performance while operating each type of MFK during simulated flight was examined. Also examined were four different arrangements of the task steps or logic levels across keyboards and the impact of both a center and side control stick location on front panel and right console MFK operation.

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FOREWORD

This Technical Report is the result of a work effort performed by the Digital Applications Group of the Crew Systems Integration Branch (FGR), Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Major Robert Bateman is the group leader and Dr. John Reising is responsible for human factors. Mr. Emmett Herron of the Bunker Ramo Corporation is tasked with providing pilot inputs to the work efforts, and Ms. Gloria Calhoun of the same company is tasked with statistical and experimental design inputs. The objective of this effort was to evaluate the use of two specific multifunction keyboards within the cockpit. The hardware was provided by AF Avionics Laboratory.

The Bunker Ramo portion of the work effort was performed under USAF Contract Numbers F33615-73C-0391 and F33615-76C-0013. The contract was initiated under Project Number 6190, "Control-Display for Air Force Aircraft and Aerospace Vehicles" which is managed by Mr. J. H. Kearns, III, as Project Engineer and Principal Scientist for the Crew Systems Integration Branch (AFFDL/FGR) Flight Control Division, Air Force Flight Dynamics Laboratory.

This effort was performed as part of the Digital Avionics Information System (DAIS) Advanced Development Program under Work Unit 20490202, and was performed in support of the Air Force Avionics Laboratory Work Unit 20030624.

This report includes work performed between 3 July 1974 and 31 December 1975.

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GLOSSARY OF TERMS

AAE - average absolute error - see Appendix F.

AE - average error - see Appendix F.

CDC 6600 - Control Data Corporation general purpose computer.

DEC 10 - Digital Equipment general purpose computer.

DEDICATED SWITCH - single switch capable of performing only one function.

DIGIT/MODE PANEL - panel with seventeen dedicated switches used in the present study for data entry and mode selection.

FIGURE OF MERIT - statistical procedure used in data analysis - see Appendix F.

FLIGHT PLAN - AF Form 70 specifying radio frequencies and waypoint coordinates.

FLYING TASK - maintaining ground speed and altitude parameters and keeping the flight director centered on the Vertical Situation Display.

FOM - see Figure of Merit.

HORIZONTAL SITUATION DISPLAY - cathode ray tube used to present navigation information.

HSD - see Horizontal Situation Display.

KEYBOARD TASK - operating the keyboards during communication changes and navigation updates.

LOGIC LEVELS - means by which pilots selected and executed tasks; each change of switch function constituted a single logic level.

MANOVA - see Multivariate Analysis of Variance.

MFK - see Multifunction Keyboard.

MPD - see Multipurpose Display.

MULTIFUNCTION CONTROLS - several multifunction switches on a single panel.

MULTIFUNCTION KEYBOARDS - several multifunction push button type switches on a single panel.

MULTIPURPOSE DISPLAY - cathode ray tube used to present various types of status information.

MULTIFUNCTION SWITCH - a switch whose function changes, depending upon the task being performed by the operator.

GLOSSARY OF TERMS (CONTINUED)

MULTIVARIATE ANALYSIS OF VARIANCE - statistical procedure used in data analysis - see Appendix F.

PDP 11/45 - Digital Equipment Corporation general purpose minicomputer.

PLASMA PANEL HARDWARE - MFK hardware in which the legend on a display adjacent to the switch changes according to the function the switch is serving at the time.

PROJECTION SWITCH HARDWARE - MFK hardware made up of switches having the capability to display different legends by selectively projecting different parts of a film strip onto the switch front surface.

RAMTEK RASTER SYMBOL GENERATOR - a display system which converts computer generated alphanumeric and graphic display information into industry compatible video signals.

RANDOMIZED BLOCK FACTORIAL DESIGN - experimental design in which each subject receives all combinations of experimental conditions. The order of administration of the treatment combinations was randomized independently for each subject.

RMS - root mean square - see Appendix F.

SD - standard deviation - see Appendix F.

STEPWISE DISCRIMINANT FUNCTION ANALYSIS - statistical procedure used in data analysis - see Appendix F.

VERTICAL SITUATION DISPLAY - cathode ray tube used to present flight information.

VSD - see Vertical Situation Display.

SUMMARY

Multifunction keyboards (MFKs) have been designed to integrate the many dedicated control functions found in present day cockpits into a more efficient arrangement. The purpose of this study was to examine pilot performance changes while operating MFKs during simulated flight. Performance in terms of maintaining flight parameters and operating the keyboards was recorded during communication changes and navigation updates. The specific test objectives were: (1) evaluate and compare two MFK hardware types - plasma panel and projection switches; (2) evaluate four different arrangements of the task steps or logic levels across keyboards; (3) assess the impact of both a center and side control stick location on MFK operation; and (4) evaluate the operation of a right console backup keyboard when a primary keyboard fails.

One conclusion reached as a result of this study was that operations other than digit entry should be consolidated on a single keyboard. Furthermore, the study showed that performance was better when the digits were entered on a separate panel. It remains to be determined whether the better performance was due to the dedicated switches or to the optimized number arrangement. The study also indicated that so long as MFK operation is not physically inhibited by the center or side location of the control stick, performance is not affected. Concerning the MFK hardware types evaluated, performance was generally better with the projection switch MFK compared to the plasma panel MFK. Operation of both types of MFKs on the front panel and right console locations is discussed. Because of design faults in the two specific keyboards provided by AF Avionics Laboratory, no attempt should be made to generalize the results of this evaluation to other keyboards. The need for further research is indicated.

SECTION I

INTRODUCTION

1. BACKGROUND

During the 1960's, there was a significant increase in the application of digital computers to the avionics subsystem of both military and civilian aircraft. The ability to miniaturize digital circuits through the use of large scale integration has enabled the avionics subsystem designer to take advantage of the flexibility of the digital computer without paying the weight penalty associated with earlier versions of general purpose digital computers. As the "digital airplane," i.e., one in which all the subsystems are managed by digital processors, approaches reality, there are some significant impacts on the cockpit. This digital capability allows the pilot access to a great deal of information. However, matching this expanded ability to process and manipulate information with the conventional approach of dedicated instruments and switches requires so many displays and control devices that cockpit size prevents the designer from getting the full value of the computer. In fact, the continued use of such controls, displays, and switches will result in a cockpit that is overloaded with dedicated devices and aircrews will pay a high workload penalty for the luxury of an on-board digital computer. As the information continues to increase, it will not be physically possible to provide for the multitude of display options with a dedicated display for each.

This increase in information to be displayed has led to the "time-shared" concept, in which the information presented on the display changes as a function of information requirements. The time-shared concept can also be extended to switches. The inherent flexibility of the digital computer allows it to change the meaning of switches as a function of mission requirements. In this way, the digital computer not only can simplify the pilot's task of performing routine functions, but also can optimize the information presentation and reduce the number of switches needed. Realization of the full power of the digital computer depends upon the ability of the pilot to interpret the different display formats and to properly select the correct multifunction switch. While the digital processors can simplify routine control functions and perform computations for the pilot, the system design must allow the pilot to exercise judgment and be able to control, in detail, all system components.

The Air Force has conducted a series of research efforts to examine the cockpit implication of digital computers (References 1, 2, 3, 4). These efforts have centered around the engineering problems involved in integrating the sensors, processors, displays/controls in the digital aircraft, and the human factors problems involved in piloting this aircraft. The human factors research initially emphasized the electro-optical display formats, but early in these research efforts it became clear that the multifunction controls were equally as important, if not more important, than the displays in determining the success of the digital aircraft cockpit (Reference 5).

A multifunction control is a panel made up of several multifunction switches; each switch is capable of performing more than one function. If the switches are push buttons or keys, the device is called a multifunction keyboard (MFK). Each switch is capable of inputting different bits of information due to the implementation of a logic network. Thus, it is essential that the pilot know the significance of each switch actuation. To accomplish this, the legend for each switch must be appropriate to the function it is serving at the time. Projection switch hardware changes a legend on the switch itself. Other mechanizations, e.g., plasma panels, change a legend on a display surface adjacent to the switch. No matter what the type of mechanization, the essential features of the MFK remain the same. Dedicated, single purpose master switches enable the pilot to establish an initial set of capabilities for the multifunction switches. Then, the multifunction switches allow the pilot to perform specific operations. For example, a plasma panel version of an MFK is shown in Figure 1. Across the top of the display

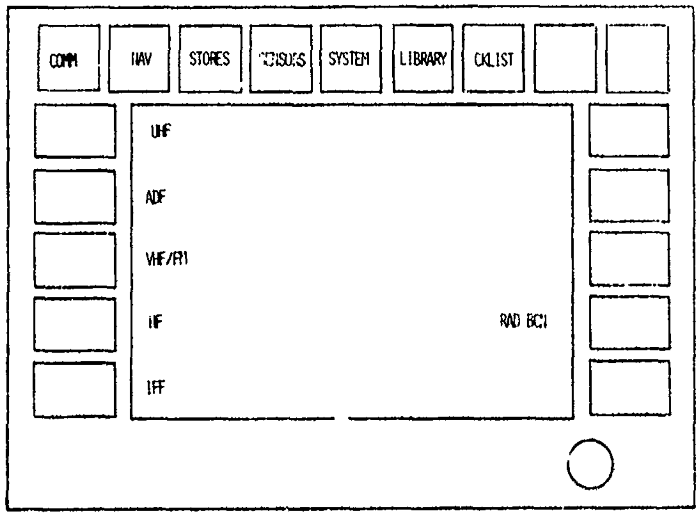


Figure 1. An Example of One Type of Plasma Panel MFK

surface are nine dedicated master switches. The multifunction switches are mounted in columns on the left and right portions of the bezel and have no legends on them. Each legend appears on the plasma panel next to the switch. The number of these legends for each switch is limited only by the memory in the digital computer. In Figure 1, the master switch labeled COMM (for communications) has been selected. Therefore, the legends appearing next to the multifunction switches indicate a variety of communication radios which the pilot may wish to control. The next step would be to select the specific radio to be operated. This selection would change the legends to appropriate titles for the multifunction switches and would allow the pilot to turn on the radio, change frequency or whatever. Each change of switch function is called a "logic level."

The MFK provides tremendous freedom for the cockpit designer in that he can allocate a number of functions to a single control panel and, thus, reduce the number of control heads and switches in the cockpit (Reference 6). This design helps the pilot by providing a single, easily reachable keyboard with which he may control several different systems. As a result, cockpit clutter is reduced, panels in hard to reach places are eliminated, and switch actions become the same, i.e., push buttons.

However, there are some issues to consider in the design of the MFK. For example, as more and more functions are located on a single control head, time sharing problems arise. The communications system provides a convenient illustration. Let us suppose the pilot were changing a UHF radio frequency immediately after takeoff in response to a request from departure control. A change in the transponder code can also be part of this request. Since the pilot doesn't have separate control heads for each of these radios, he must initiate and proceed through the COMM/UHF sequence to change frequency and then go back and do the same for the COMM/IFF sequence to change code. A worst case would be generated when, halfway through one task, a pilot was required to initiate another task. Problems may also arise if operators become "lost" in a maze of logic trees or forget where they are. The extent of these problems remains to be determined. The crew station designer must be fully aware of these problems when designing the MFKs. One solution to the single panel problem is to use two identical MFKs, thereby providing the capability to start a task on one MFK; stop that task to initiate and complete a task on the second MFK; and then return to the first MFK and complete the first task. Such a system would still occupy less space than the many control panels that are currently used. The use of two MFKs by allocating half of the functions to each control panel would also be a solution.

Another issue to be considered when discussing MFKs is redundancy. What happens if the CRT becomes inoperative? What if a master function switch fails in either open or closed position? What if a multifunction switch breaks? Such possibilities make the inclusion of a second MFK attractive. The inclusion of an identical second MFK may be the best solution (given that space constraints or computer limitations do not rule it out) since complete redundancy is achieved and the pilot can operate functions separately on each keyboard. The final solution as to which back up capability is best depends upon, among other things, the type of control stick used. Control stick location impacts the pilots' reach envelope, thus the placement of a second MFK may vary if a side stick is used instead of the conventional center stick.

2. PURPOSE

The MFK has been designed to integrate the many dedicated control functions found in present day cockpits into a more efficient arrangement. The purpose of this study was to examine pilot performance changes while operating MFKs during simulated flight. The following specific factors related to MFK operation were investigated:

a. MFK Hardware Type

Three types of keyboards were used. The main thrust of the investigation was to compare two of these (projection switch MFK with a plasma panel MFK). For each task, one of the MFKs was mounted on the front panel and the other MFK was mounted on the right console. Both MFKs were evaluated in both locations (Figures 2 and 3). Each of these two keyboards was used in conjunction with a dedicated third keyboard for some tasks. This dedicated keyboard included switches for mode selection and for digit entry, hence, it was referred to as a Digit/Mode Panel. It was always located on the left console (see Figures 2 and 3).

b. Logic Level Arrangements

Each task, whether a communication change or a navigation update, required a four step operating sequence. Each step in these operating sequences is called a logic level. For example, in the present study, the pilot had to go through the following four steps or logic levels to change a UHF radio frequency:

Step 1 - select the communication function from all other functions on the keyboard.

Step 2 - select the UHF radio from among the other radios on board the aircraft.

Step 3 - select the frequency change function from among the other functions of the UHF radio.

Step 4 - enter the appropriate frequency.

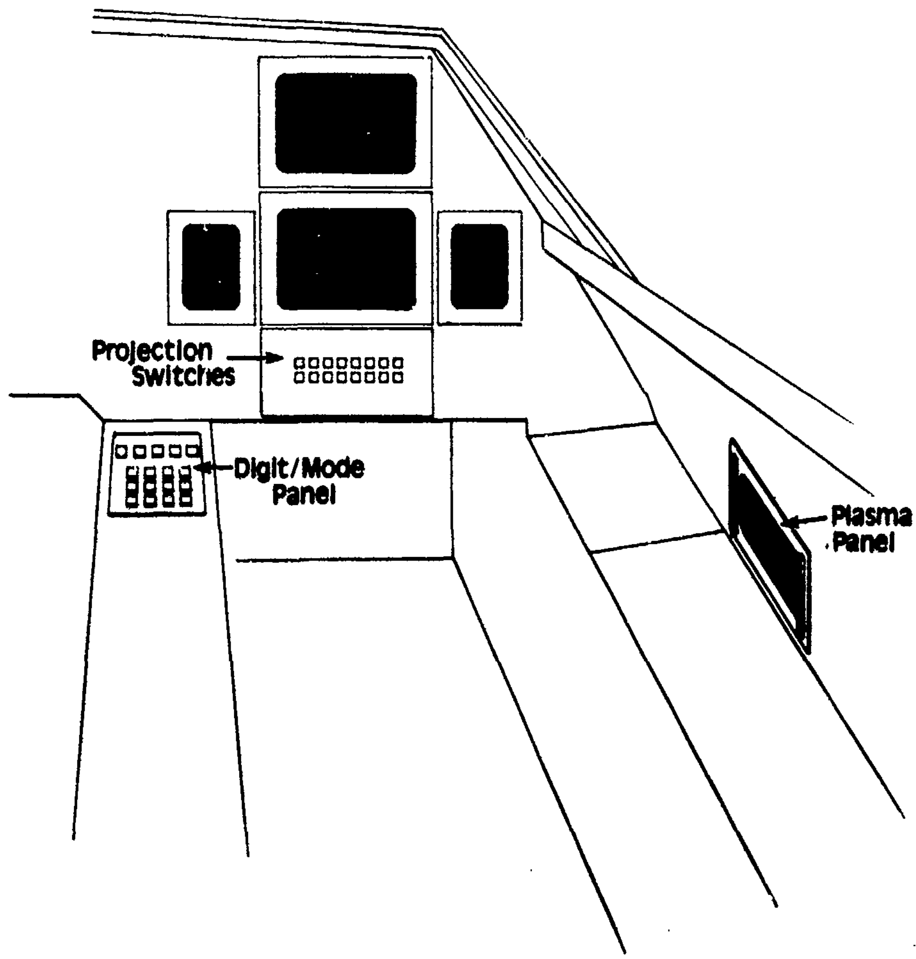


Figure 2. Cockpit Configuration with Front Panel Projection Switch MFK and Right Console Plasma Panel MFK

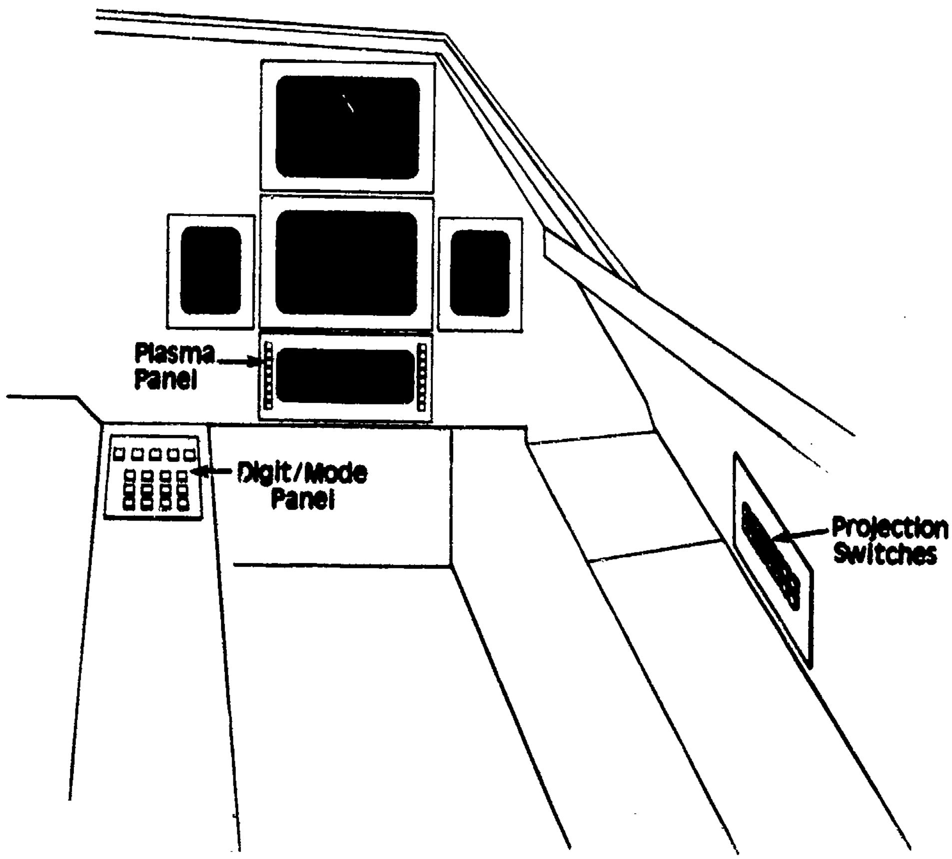


Figure 3. Cockpit Configuration with Front Panel Plasma Panel MFK and Right Console Projection Switch MFK

Each MFK had the capability for all four levels of systems control and information, whereas the Digit/Mode Panel, had only the capability to function for logic levels 1 and/or 4. This study examined logic level arrangements in terms of whether operations of the four logic levels should be performed on one keyboard only (one of the MFKs) or two keyboards (divided between one of the MFKs and the Digit/Mode Panel). Figure 4 shows the four different logic level arrangements, lettered A through D, which were investigated.

c. Control Stick Location

Another factor investigated in relation to MFK operation was the effect of both a center and side control stick location on the operation of the MFKs (Figure 5). The distinction should be made that it was not the intent of this study to evaluate differences in stick location, but rather the effects of stick location on MFK operation. The MFK being evaluated in the front location was designated as "primary" for a task. When failures of the primary MFK were introduced, the other MFK, mounted on the right console, was used as a "backup". It was expected that a center stick would tend to interfere with the primary MFK and that a side stick would tend to interfere with the backup MFK (Figures 6 and 7).

d. Degraded Mode Performance Between MFKs

One crucial drawback to the MFK is the loss of capability with keyboard failure. This study dealt specifically with this problem in that it studied the operation of backup MFKs to be used when the primary keyboard fails. Operation during normal modes involved either the front instrument panel MFK or the front instrument panel MFK and the Digit/Mode Panel. Failed modes involved operation of either the right console MFK or the right console MFK and the Digit/Mode Panel. Failures were initiated only between task events. During a failed mode, either the front panel MFK or the Digit/Mode Panel, became inoperative. The logic levels (Figure 4) that had been on that keyboard then became operable on the right console backup MFK (Figure 8). Both the projection switch and plasma panel type MFK were examined in the right console location during failed conditions.

e. Additional Cockpit Design Factors

In addition to obtaining subjective evaluations on the four areas just discussed, subjective evaluations were also obtained on the display formats, the use of a pre-entry readout, and control actions required to correct erroneous entries.

NORMAL CONDITION

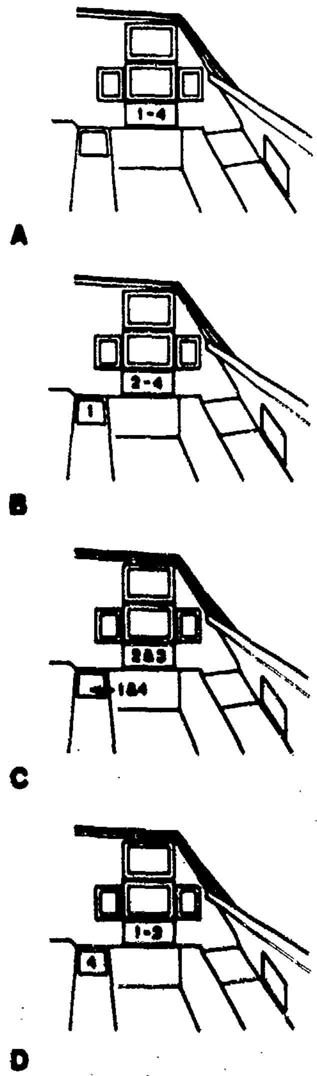


Figure 4. Four Logic Level Arrangements for Performing Steps in the Normal Operating Sequence

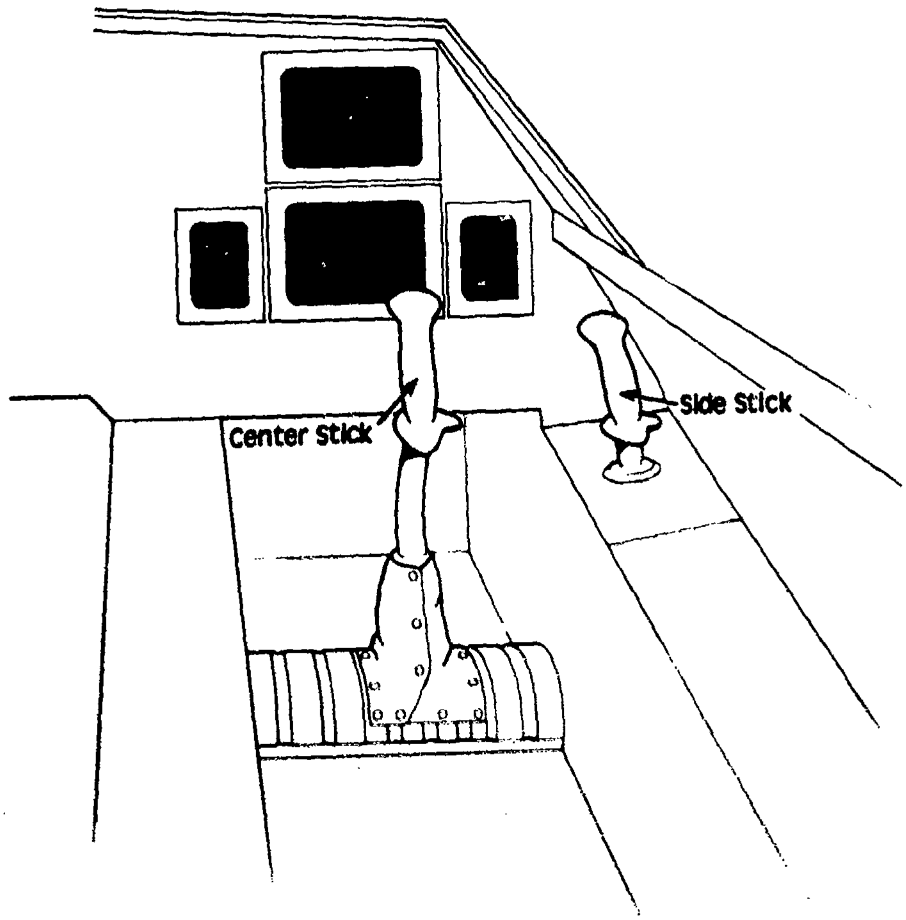


Figure 5. Location of Center Stick and Side Stick Flight Controllers. Note: Only one controller was in place at one time.

Figure 6. Relationship of the Center Control Stick to the Front Panel MFK

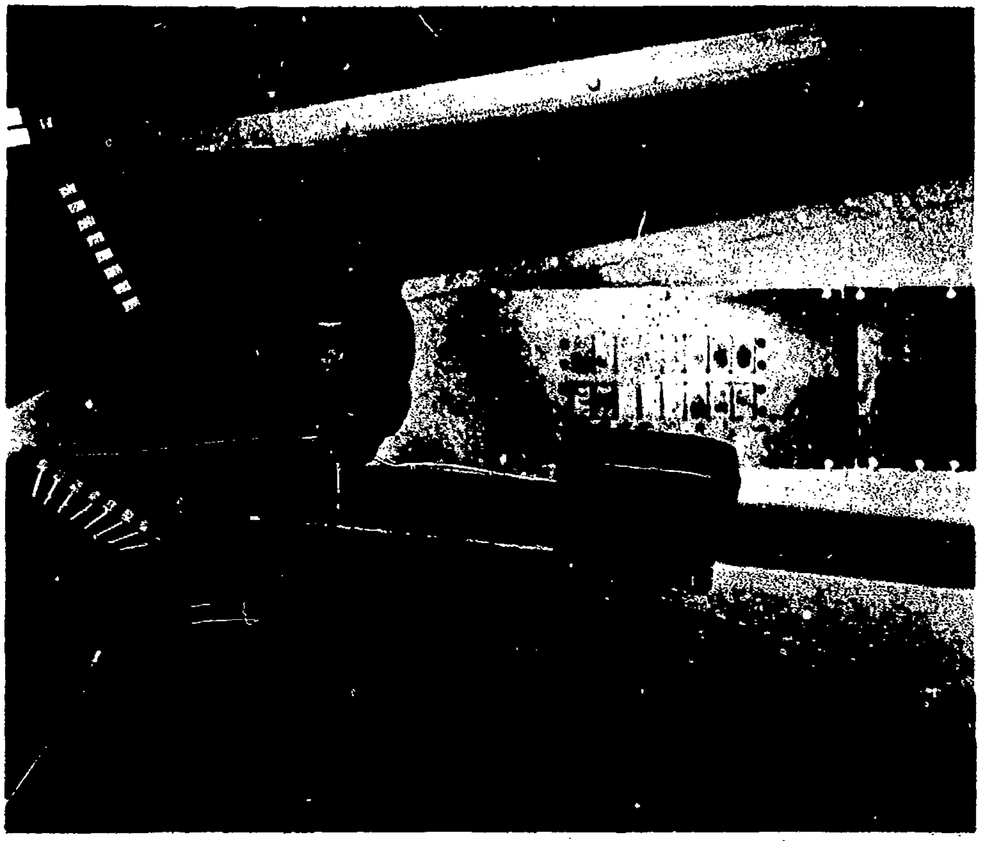


Figure 7. Relationship of the Side Control Stick to the Right Console MFK

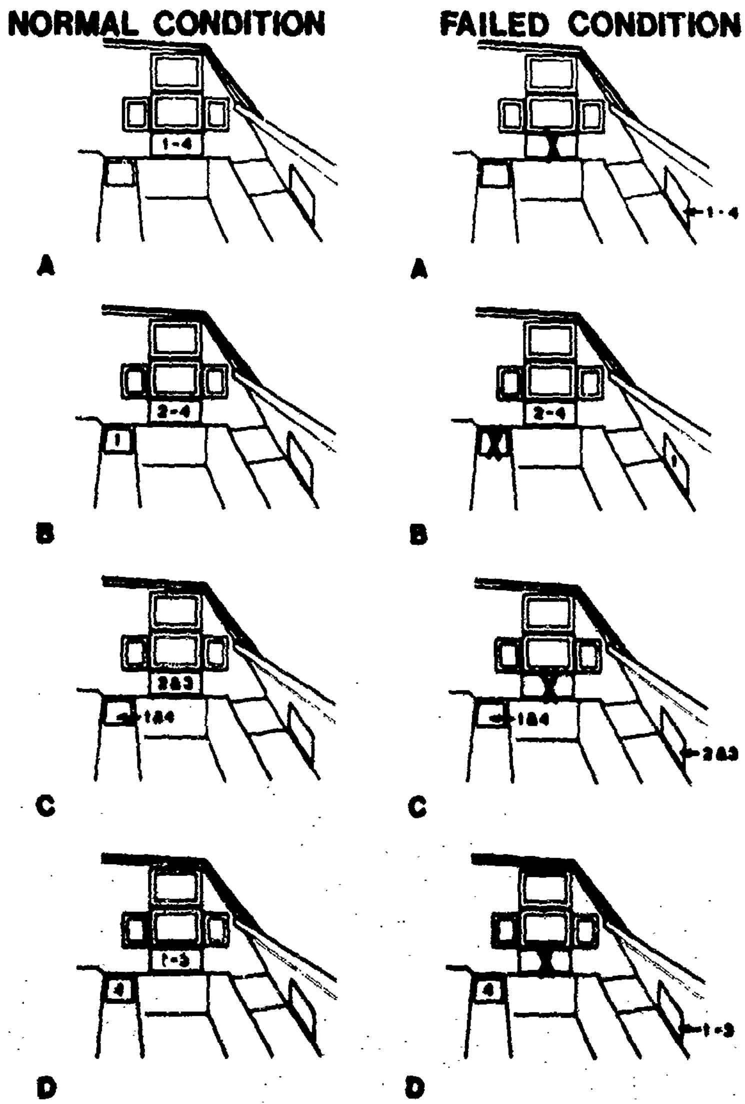


Figure 8. Four Logic Level Arrangements for Performing Steps in the Operating Sequence Under Normal and Failure Conditions

SECTION II

APPARATUS

A two-place, side-by-side cockpit simulator of F-111 dimensions, was fabricated to accomodate the electro-optical displays and MFKs. The cockpit layout is shown in Figure 9. The subject pilot was seated in the right side of the cockpit while the left seat was occupied by an experimenter. The controls and displays for the left seat were not activated.

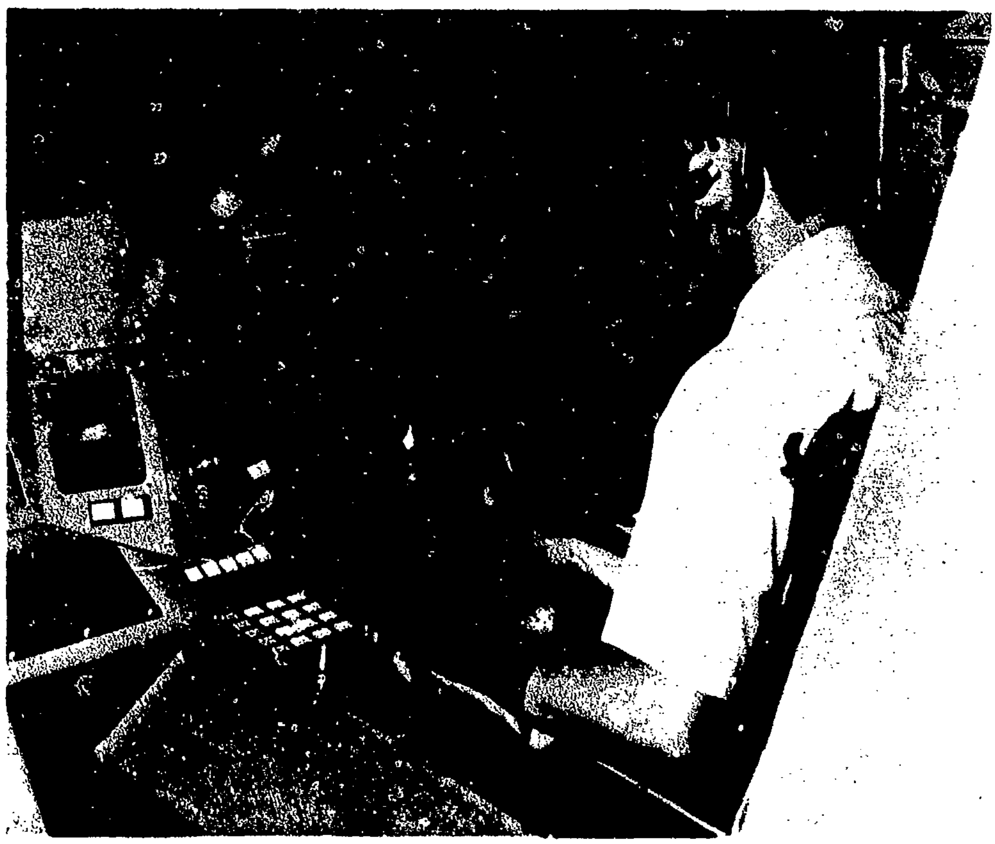


Figure 9. Cockpit Simulator Used in the MFK Evaluation

1. KEYBOARD CONFIGURATION

a. Description

Two types of MFKs and one dedicated keyboard were utilized in the present study. They were as follows:

(1) Projection Switches

One MFK consisted of sixteen push button projection switches (Figure 10). Each switch had twelve possible legends. The legends were programmed to inform the pilot of the four levels of systems control available. Only those switches displaying information were operable.

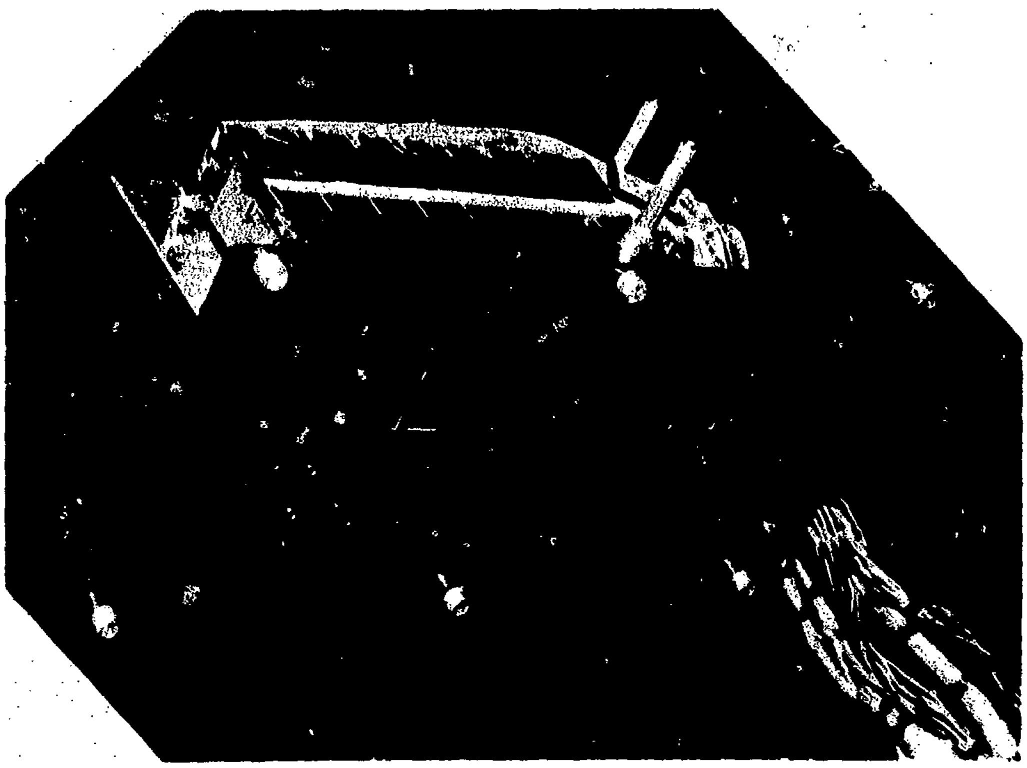


Figure 10. Projection Switch MFK

(2) Plasma Panel

The other MFK utilized a plasma panel with sixteen peripheral push-button switches (Figure 11). Each switch was associated with a legend located on the plasma panel. Due to the relative difference in sizes of the switches and plasma panel, the legends were not directly adjacent and in line with the corresponding switches. Therefore, each switch was associated with the appropriate legend by a white line. The switches were operable only when information was displayed adjacent to the switches on the plasma panel. The plasma panel MFK and projection switches MFK were functionally redundant.

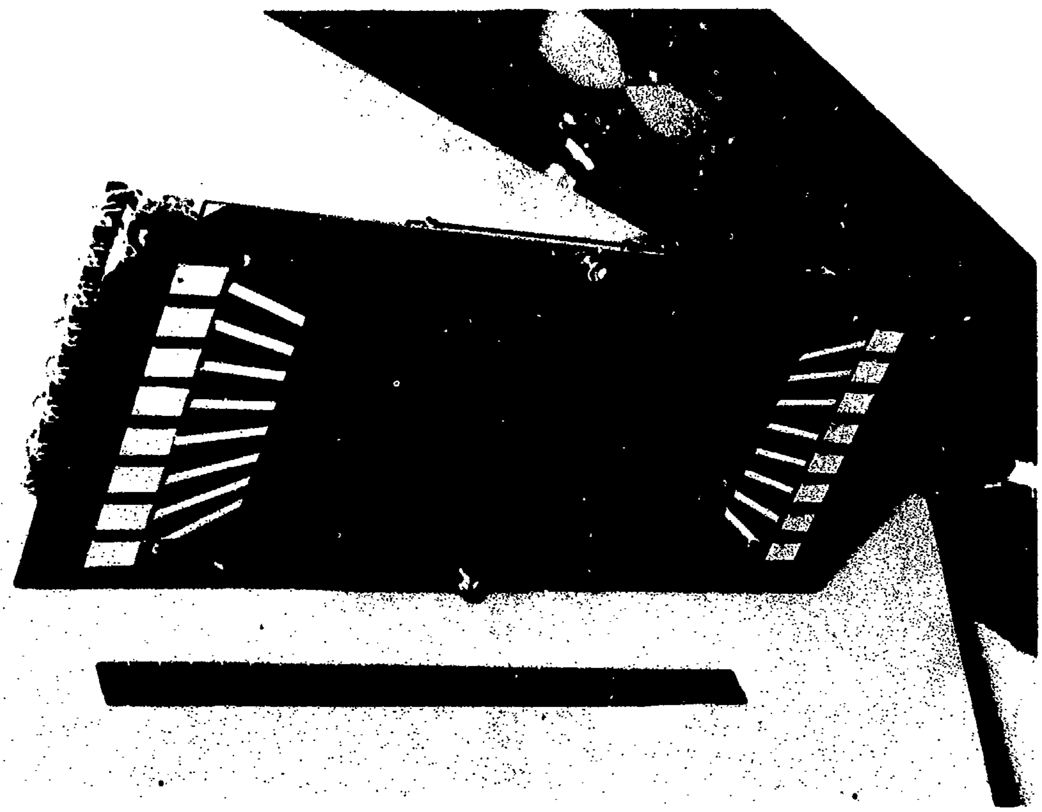


Figure 11. Plasma Panel MFK

(3) Digit/Mode Panel

The digit/mode panel consisted of seventeen dedicated push button switches. Twelve of the keys served as a data entry panel; five served as mode select keys. The five switches were backlighted to indicate mode selected (green-selected, white-not selected).

b. Location

The dedicated digit/mode panel was mounted forward of the throttle. Each type of MFK was mounted on the front panel during half of the flights and on the right console during the other flights. Thus, the operation of each MFK type, both as a primary (front instrument panel) keyboard and as a backup (right console) keyboard, could be examined.

c. Keyboard Logic Levels

As previously mentioned, logic levels were the means by which the pilot selected and executed a particular task. Four logic levels were required for the communication (COMM) and navigation (NAV) tasks performed by the pilot in this study. During the first logic level step, the pilot selected either COMM or NAV from the five available modes. Activation of the mode selection switch brought up logic level 2 under that mode. Activation of a control at logic level 2 changed the panel to logic level 3 and presented options appropriate to that task. Activation of a control at level 3 enabled data entry at logic level 4. Figures 12 and 13 show a typical communication change sequence, legends used, and legend location for the projection switches and plasma panel MFKs, respectively. Similarly, Figures 14 and 15 illustrate the logic level steps, legends used, and legend location for each MFK type, to complete a navigation update. It should be noted that the selection of legend location was made by AF Avionics Laboratory and hardware/software constraints made changes impractical.

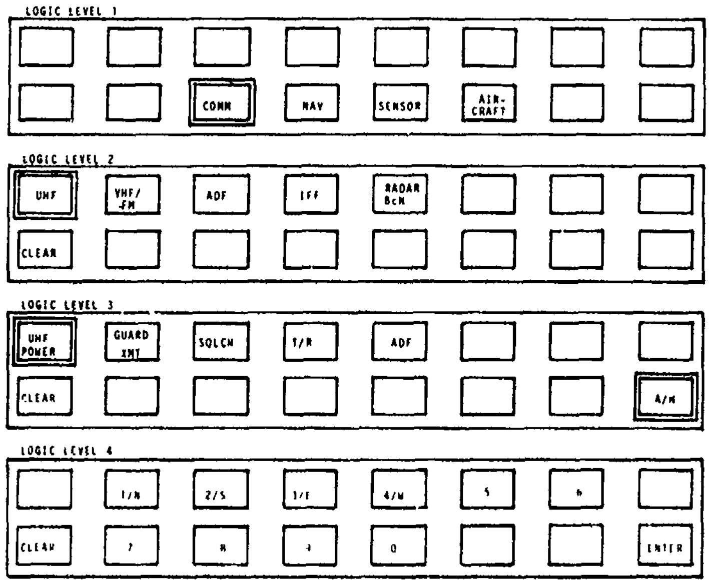


Figure 12. Projection Switch MFK Communication Change Sequence

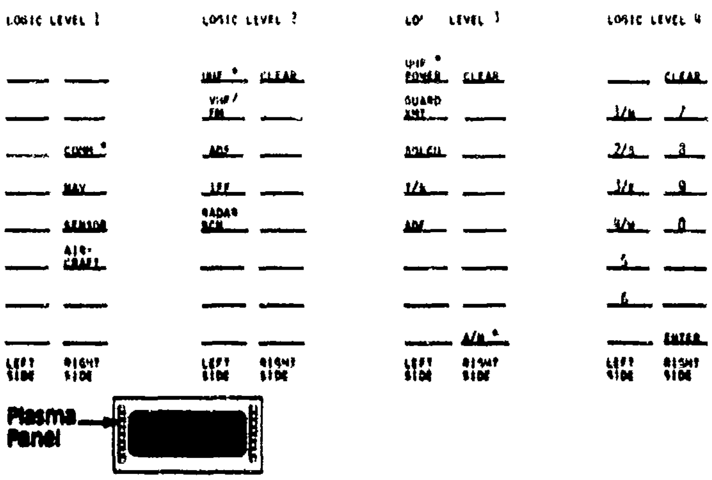


Figure 13. Plasma Panel MFK Communication Change Sequence

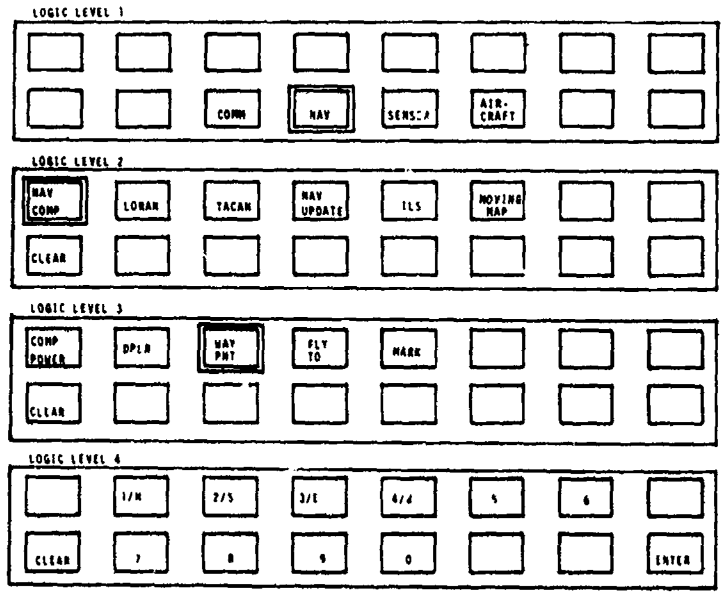


Figure 14. Projection Switch MFK Navigation Update Sequence

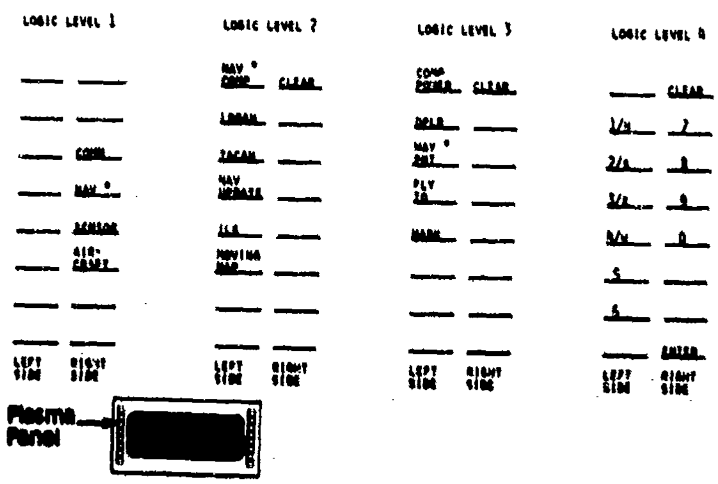


Figure 15. Plasma Panel MFK Navigation Update Sequence

2. COCKPIT CONFIGURATION

Four electro-optical displays were used in the present study to provide information to the pilot (Figure 9). The Vertical Situation Display (VSD) was presented on a color CRT and was essentially an electro-optical Attitude Director Indicator (ADI) (Figure 16). The Horizontal Situation Display (HSD) was presented on a nine-inch diagonal monochrome CRT and consisted of a representation of the route of flight (Figure 17). Two Multipurpose Displays (MPDs) were used to provide either communications or navigation data on the left, and either engine data or keyboard failure data on the right (Figures 18 through 21). For a more complete description, see Appendix A.

Other controls included (a) flight mode select panel--only the cruise mode was used in this study, (b) landing gear control panel--landing gear handle was not operational--speed brakes and flaps were operational, and (c) pitch indication zeroing switch--activation of this blue-lighted push button switch aligned the horizon line with the aircraft symbol.

Thrust was controlled by a left-side, slide-control throttle. Bank and pitch commands were input either by means of a center stick mounted on the floor or a side stick mounted on the right console. The side stick configuration included an armrest. Both center and side stick had conventional trim buttons and a microphone button.

3. EXPERIMENTER'S CONSOLE AND SIMULATOR FACILITIES

These items are described in detail in Appendix B. They were designed to allow the experimenter to initiate tasks and control failures in a realistic fashion, yet allow automation of the test configuration details.

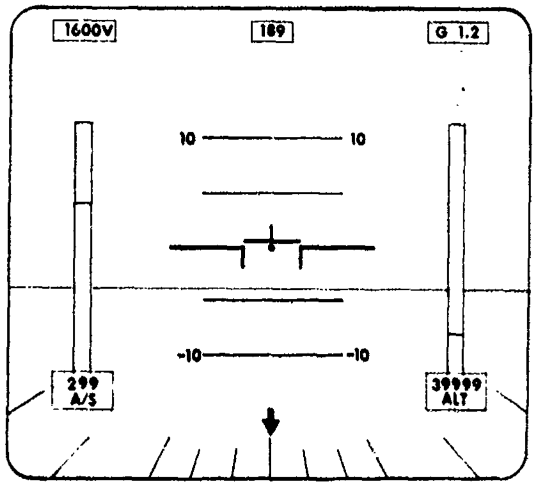


Figure 16. Vertical Situation Display (VSD) Format

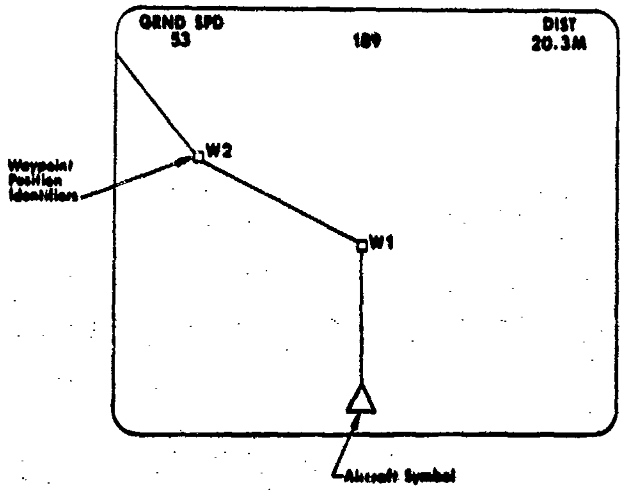


Figure 17. Horizontal Situation Display (HSD) Format

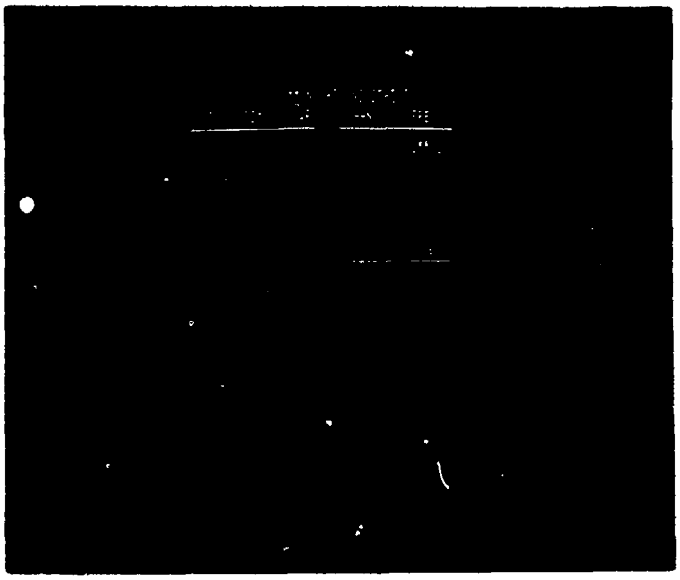


Figure 18. Multipurpose Display (MPD) with a Communication Status Format

Figure 19. Multipurpose Display (MPD) with a Navigation Status Format

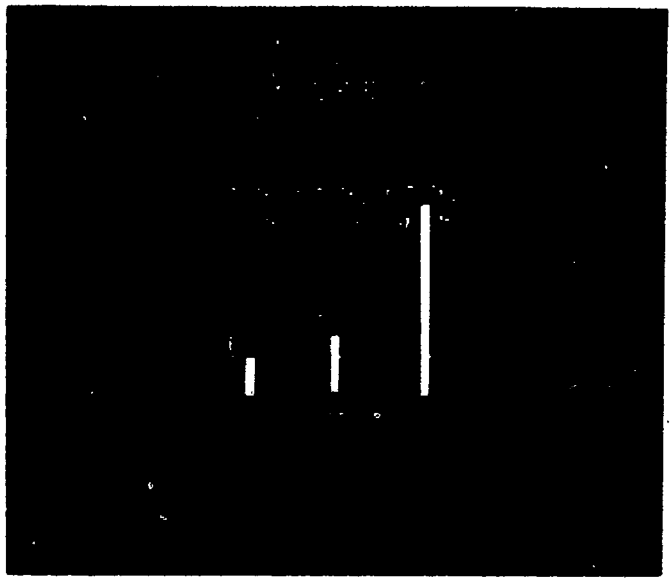


Figure 20. Multipurpose Display (MPD) with Engine Status Format

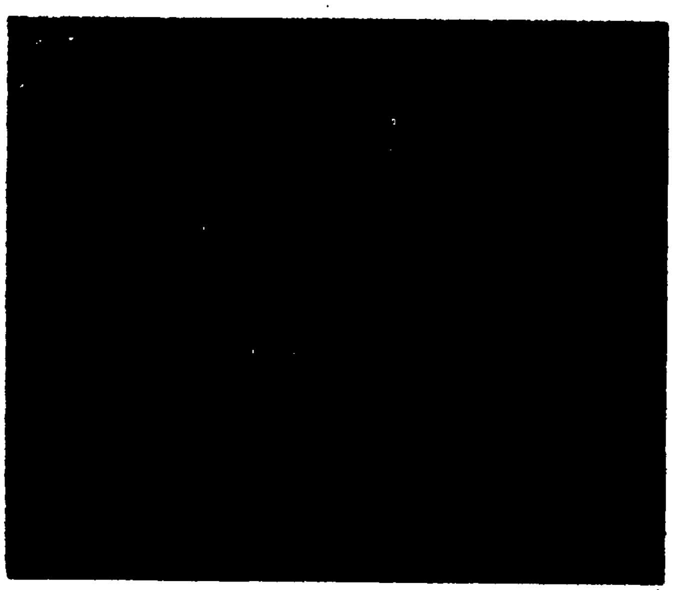


Figure 21. Multipurpose Display (MPD) with MFK Failure Format

SECTION III

TEST METHOD/APPROACH

1. TEST OBJECTIVES

The purpose of this study was to examine pilot performance changes while operating MFKs during simulated flight. The specific test objectives were: (1) evaluate and compare the two MFK hardware types - plasma panel and projection switches; (2) evaluate four logic level arrangements in terms of whether the logic levels should be located on one keyboard (MFK only) or two keyboards (MFK and Digit/Mode Panel); (3) assess the impact of control stick location on MFK operation; and (4) evaluate the performance of a right console, backup keyboard when a primary keyboard fails. The test design provided for analyses of: (1) several objective performance measures for four flight parameters and (2) two objective performance measures for keyboard operation. Questionnaire data was also obtained on these same factors.

2. TEST CONFIGURATION

A Randomized Block Factorial Design (Reference 7) was used in this study. The design involved the following three independent variables: (1) two locations of the control stick (center and side location); (2) two types of keyboard hardware (plasma panel and projection switches); and (3) four different logic level arrangements. Each of the nine subject pilots was scheduled to fly twenty-four test flights. Sixteen of these flights required failed mode operations in order to evaluate use of the backup keyboard. The remaining eight flights were scheduled without failures. The normal and failed mode flights were randomly distributed for each pilot so that the pilots were less likely to anticipate failures. Specific task order and route of flight were independently randomized for each subject pilot. Hardware location, logic level arrangement, and stick location were also independently randomized and balanced for each pilot. In order to reduce changes of hardware components, each pilot flew the twenty-four test flights in groups each consisting of four or five consecutive flights with the same keyboard and control stick configuration. The order in which each pilot was scheduled to fly these groups of flights was random. (See Appendix C for daily test schedules.)

3. TEST SUBJECTS

A total of nine pilots served as volunteer subjects in this experiment. Seven were current pilots from the 4950th Test Wing of the Aeronautical Systems Division located at Wright-Patterson AFB, while the other two, while not currently assigned flying duties, had extensive flying experience. The subject pilots had an average age of 29 years and an average of 1,805 flying hours.

4. TEST PROCEDURE

a. Pilot Briefing

During the first two hour session, each pilot was given a fifteen minute briefing regarding the purpose of the study. Included in the briefing was a discussion concerning an advanced "digital" airplane cockpit and specific explanations of the controls and displays. After answering any questions the pilot might have had, the experimenter took the pilot to the simulator for an additional briefing.

b. Cockpit Briefing

A structured outline was followed during the cockpit briefing to standardize training procedures, thus, ensuring that each pilot received the same information and the same opportunity for cockpit familiarization. The thirty minute briefing included the following: (a) an explanation of location and types of keyboards and displays; (b) the detailed operation of the keyboards in respect to the logic level arrangements during both normal and failed modes of operation; (c) and specific navigation/communication tasks each pilot would be required to perform. In addition, the display formats and operation of cockpit controls were explained. The pilot was also required to complete some tasks involving use of the keyboard prior to the actual training flights.

c. Training Flights

Following the pilot's familiarization with the cockpit simulator, four training flights, one with each logic level arrangement, were conducted in order to give the pilot experience with the handling qualities of the simulator and operational procedures of the test conditions. During the flights, the pilot completed communication and navigation tasks under normal conditions using the primary keyboard(s) and under failed conditions using a right console keyboard. Observation of the pilots' performance revealed that forty minutes of training was adequate to enable them to control the simulator and operate the keyboards. Four of the pilots were selected randomly and trained with the projection switches as the primary keyboard; the other five were trained with the plasma panel as the primary keyboard. Similarly, four of the pilots were selected in a separate random process and trained with the control stick in a center location, while the others were trained with the control stick in a side location. The alternative locations of the keyboard and control stick were pointed out to the pilot.

d. Test Flights

At the initialization of each flight, the displays were in the following configuration: (a) VSD - Flight parameters were appropriate to that of level flight in a cruise mode with an altitude of 20,000 feet and indicated airspeed of 301 knots. (b) HSD - Aircraft position was approximately seven miles short of waypoint 1 (Figure 17); the heading was the same as that for the first leg. The ground speed was at 420 knots. (c) Left MPD - Communications status format was displayed. (d) Right MPD - Engine status format was displayed. The SENSORS mode at logic level 1 had been activated on the appropriate keyboard.

Throughout each flight, the information displayed on the VSD and HSD was dynamic in response to thrust, bank, and pitch inputs. However, the flight director on the VSD was inoperable until the pilot crossed waypoint 1. Selection of COMM or NAV on the appropriate keyboard determined whether communication or navigation status was displayed on the left MPD. When displayed, the navigation status on the left MPD constantly presented new information such as aircraft position, time and distance to the next waypoint, etc. Also, the communication format display presented the status of the communication radios. The pilot's flying task was to maintain ground speed and altitude during 70-80 miles of flight and keep the flight director symbol centered on the Vertical Situation Display. (See Appendix D for flight information.) The pilot's keyboard task was to complete two communication changes and two navigation updates. These tasks were felt to be analogous to the pilot's flying a single seat fighter aircraft.

Prior to each flight, the pilot was given a Flight Plan (AF Form 70) specifying radio frequencies. Fifteen UHF radio frequencies were each identified by a letter. Instructions to change a new frequency were given orally, using controller-to-pilot radio terminology. By identifying the new frequency by letter, errors due to forgetting or misunderstanding a four-digit sequence were eliminated. The random assignment of frequencies from the list of fifteen prevented the pilot from anticipating or memorizing the new frequency prior to task assignment. The waypoint coordinates to be entered were also listed on the AF Form 70. Since their length, and the uncertainty of whether the next task was COMM or NAV tended to preclude memorization, extra waypoints were not included. Instructions to enter or "update" a waypoint were given by a controller, using standard terminology and by identifying the waypoint with a single number. When the pilot updated the waypoint, he entered both the waypoint number and the latitude/longitude coordinates. The experimenter did not initiate these tasks while the pilot was banking or before waypoint 1.

The appropriate keyboards were inoperative until activated by the experimenter. Activation of the following switches was required for a navigation update: NAV, NAV COMP, WAYPT, and the appropriate digits. If an incorrect switch was pushed in levels 1, 2, or 3, legends unrelated to the requested task appeared on the keyboard. In order to complete the required task, the pilot had to correct the mistake. To accomplish this, the pilot pushed the CLEAR switch once to return the keyboard to the previous level and then made the proper selection. Once the pilot reached the fourth logic level step, a pre-entry readout of each selected digit was available on the navigation MPD format. If an erroneous digit was detected, the pilot pushed the clear switch. This action erased all the digits making reselection of each and every digit necessary. In the opinion of the experimenters, this was not the optimum error correction method but was retained for the experiment due to time restrictions and for the purpose of gathering data on its use. When the pilot pushed the ENTER button, the computer interpreted the digits selected and determined their accuracy. If the pilot had pushed an incorrect digit, the error message, "INCORRECT DIGIT ENTRY, RE-ENTER," was presented at the top of the display and the keyboard returned to the third level. In order to complete the task, the pilot had to push WAYPT again to activate the digits and repeat the entry. Once the correct information was entered, the keyboards returned to SENSORS at logic level 1 and the format for navigation status was displayed on the left MPD.

For a communication change, activation of the following switches was required: COMM, UHF, and UHF POWER, A/N, and appropriate digits. Both UHF and UHF POWER switches were selected at step 2. However, during the second communication change of each flight, the UHF power remained active so that the required switch sequence became: COMM, UHF, A/N, and digits. The MPD/keyboard changes and related procedures of a communication change were similar to that of a navigation update. These procedures differed, however, if a pilot entered an incorrect frequency that was still within the normal UHF frequency range. In this case, the keyboard returned to the third level but no error message was presented on the MPD. The pilot was then notified by the experimenter to redo the task.

Concerning the normal/failure status of the configuration, each flight was initialized in a normal mode. A change of the normal/failure status did not occur during task events. When the experimenter changed the configuration to a degraded mode, the master caution light located to the left of the VSD flashed orange. When the pilot acknowledged the failed state by pushing the master caution light, the flashing stopped. Concurrently, a primary keyboard became inoperable and the logic levels that were on the keyboard were presented on the right console keyboard. When a failure occurred, the display on the right MPD was replaced with the failure message. This format specified which keyboard was failed and the logic levels that were operable on the right console, backup keyboard. When the experimenter returned the cockpit to a normal mode, the master caution light flashed green, the primary keyboard became operable, the right console keyboard became inoperable, and the information displayed on the right MPD indicated that normal operation was reinstated.

In order to determine the effect of keyboard operation on a pilot's ability to fly the aircraft, flight task parameters were sampled twenty times per second. Further data concerning keyboard operation was obtained by recording the time required to complete a task event and the number of switch hits that occurred during the task event. For purposes of statistical analysis, a task event was defined as follows: (1) the pilot was given a request for a communication change or navigation update by the experimenter. (Note that contrary to usual flight procedures, the pilot had to wait for a request from the experimenter prior to making a navigation update. This procedural change was explained to the pilot. The pilot was required to respond to each command and complete the keyboard operation as soon as possible.) (2) The experimenter pushed an event marker switch concurrent with the pilot's acknowledgement of the instructions. Since pilot acknowledgement tends to be nearly automatic, this increases the probability that time for mental processing and decision was included in the task event time. (3) If the keyboard data was entered, but was incorrect (i.e., wrong frequency or waypoint coordinate entered), then the pilot was required to redo the necessary procedure until it was successfully completed. Time to complete the task and number of switch hits were measured for each event from the time the pilot responded to the event command until he completed the sequence correctly. An upper bound of four minutes was operationally defined by the experimenter as the maximum time allowable for a keyboard operation.

e. Debriefing

Following the completion of the data flights, each pilot completed a form concerning his background flying experience. The pilots also filled out a questionnaire designed to elicit subjective evaluations concerning each of the four logic level arrangements, the location of the control stick, location of the keyboards, and display formats (Appendix E).

5. PERFORMANCE MEASURES AND DATA ANALYSIS

The following flight parameters were recorded twenty times per second on magnetic tape:

Ground speed (knots)
Altitude (feet)
Flight director deviation from null (arbitrary units)

Appropriate summary statistics (average error (AE); average absolute error (AAE); root-mean-square error (RMS); standard deviation (SD) [see Appendix F for formulae]) were computed on these flight parameters for the time period specified by the event and for the immediate fifteen seconds prior to the event. The fifteen second pre-event time was designated as baseline performance. Summary statistics for baseline performance for each parameter were subtracted from the corresponding values recorded during the event in order to measure only the effect of the keyboard tasks on the pilot's performance. This difference score quantified the level of the flying task performance decrement expected due to keyboard task performance. Keyboard task performance was evaluated by measuring the time required for the task and the number of switch hits. Since switch hits were not the same for COMM and NAV tasks, a Figure of Merit (FOM) was computed by dividing the actual number of switch hits by the number required to accomplish the task without error. For an example computation, see Appendix F. An error free task would produce a FOM of 1.0. As errors increased, the FOM would increase.

The data were initially analyzed by multivariate analysis of variance (MANOVA) using the BMD 12V statistical program available on the CDC 6600 computer. In those cases where the MANOVA revealed significant effects, subsequent analyses were conducted by stepwise discriminant function analyses (BMD07M) in order to determine which of the dependent variables were most sensitive to changes in independent variables. The eight dependent variables which were selected for these analyses are indicated in Table 1 by an asterisk.

TABLE 1

SUMMARY STATISTICS FOR EACH DEPENDENT VARIABLE

The following is a list of the summary statistics calculated for each of the six performance variables recorded during the tasks.

	Dependent Variable	Summary Statistic
1	Altitude (feet)	AE
* 2		AAE
*$ 3		RMS
4		SD
5	Ground speed (knots)	AE
* 6		AAE
*$ 7		RMS
8		SD
9	Cross track error (arbitrary units)	AE
10		AAE
11		RMS
12		SD
13	Bank error (arbitrary units)	AE
* 14		AAE
*$15		RMS
16		SD
*$17	Keyboard operation time (seconds)	
*$18	Switch hits error (figure of merit)	

* Variables analyzed by multivariate analysis of variance and discriminant function analyses.

$ Variables used in the analysis of work discussed in paragraph III-5 and Appendix G.

In the first phase of the data analysis, communication changes were examined separately from navigation updates, since it was felt that the navigation updates were more demanding and, hence, would serve as a better indication of any treatment effects. In addition, since it was felt that the keyboard operations completed during failed modes were more demanding than those completed during normal modes, analyses of the failed mode keyboard operations were conducted separately from normal. This four-fold categorization resulted in communication changes - failed mode, navigation updates - failed mode, communication changes - normal mode, and navigation updates - normal mode. In order to analyze these data, four separate MANOVAs were run.

In regards to the debriefing questionnaire, data obtained was compiled to be presented in tabular form and appropriate summary statistics were calculated. The biographical data obtained from the flight experience questionnaire was also evaluated with descriptive statistics to obtain an overall view of the characteristics of the pilot sample.

A work analysis, described in Appendix G was conducted to assess the total effect measured by changes in all of the dependent variables. The output of this analysis is a nondimensional number that is related to the percentage of work.

SECTION IV

RESULTS

The results of the statistical analyses conducted on the objective performance measures are presented for each of the following areas of investigation:

a. MFK hardware type

b. Logic level arrangement

c. Control stick location

Within each area, the results of the keyboard operations completed during failed conditions are presented first, followed by the results for tasks completed during normal conditions. In each case, the results for navigation updates are discussed separately from that for the communication changes.

1. MFK HARDWARE TYPE

a. Navigation Updates Completed Under Failed Conditions

The results of the MANOVA of the navigation tasks completed under failed conditions revealed a significant hardware main effect (F = 3.22, df = 8, 17, p < .05). A stepwise discriminant analysis indicated that pilot performance was better when the projection switches were used and that the bank AAE was the dependent variable most sensitive to differences between the two hardware types (F = 4.23, df = 1, 142, p < .05). However, this difference must be viewed considering a hardware type by logic level arrangement interaction (F = 2.34, df = 24, 49.91, p < .01). This interaction indicates that the optimal keyboard type was determined by which of the four logic level arrangements was in use. The logic level arrangement variable as a factor in this interaction is presented in more detail in Section IV-2a. A subsequent stepwise discriminant analysis indicated that keyboard operation time was the dependent variable most sensitive to the variables in the logic level by hardware interaction ($\underline{F}$ = 3.82, $\underline{df}$ = 7, 136, $\underline{p}$ < .01). The keyboard operation time for pilots to complete navigation updates during failed conditions is shown in Figure 22 for each logic level arrangement as a function of MFK type. As illustrated in the figure, keyboard operation time on the right console MFK was faster with the projection switches than with the plasma planel for logic level arrangements A, C, and D. In the case of logic level arrangement A, which involved digit entry on the right console MFK during failed conditions, the difference between the projection switches and the plasma panel was significant ($\underline{p}$ < .01). In other words, keyboard operation time was worse when the pilot had to input digits on the right console plasma panel keyboard. Results for logic level arrangement B, however, indicated that while not statistically significant, keyboard operation time was slightly slower with the projection switches on the right console than with the plasma panel ($\underline{p}$ < .25). Inspection of Figure 8 shows that for failure conditions, logic level arrangement B involved the use of the opposite hardware types

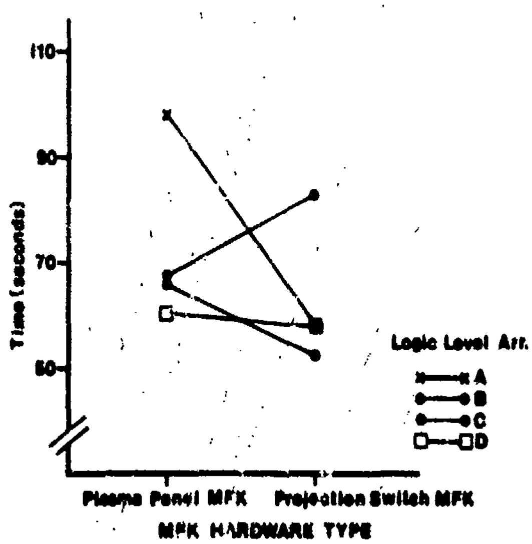


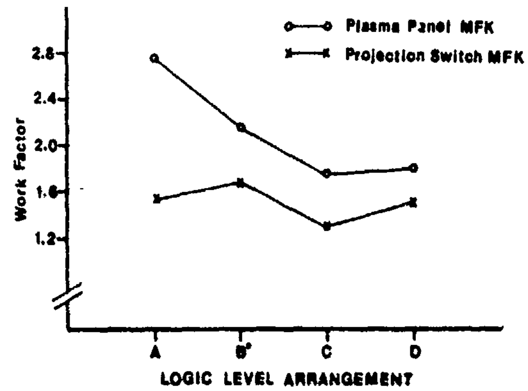
Figure 22. Mean Keyboard Operation Time Required for Completion of Navigation Updates During Failed Conditions with each Logic Level Arrangement as a Function of MFK Hardware Type

for three of the four steps. With this in mind, it can be stated that, for logic level arrangement B in the failed condition, the increased time required for "projection switches" was accounted for by the fact that the plasma panel located on the front instrument panel was used for all but the first entry!

For these navigation tasks, with failed panels, the analysis of work showed that the work required with a plasma panel was nearly twice standard (work factor = 1.99) while the increase when using projection switches was only 1.63 times the standard. According to the classification scheme used, the logic level arrangements involving either a failure of the front panel MFK or the digit/mode panel were identified by the type of hardware mounted on the right console. For example, in the case of logic level arrangement B in which the plasma panel MFK is mounted on the right console, the classification scheme designates this configuration as operation of the plasma panel MFK under failed conditions. Inspection of Figure 8 indicates, however, that this arrangement required greater use (three of the four logic levels) of the front panel projection switch MFK than the right console plasma panel MFK. Therefore, the results of the analyses conducted using this classification system do not really reflect operation of the right console panel since most of the switch actions were completed on the front panel. This discrepancy occurred only with logic level arrangement B. If the classification system is changed such that each configuration is identified according to which MFK hardware was used to complete the majority of switch hits, the plasma panel work required is 2.12 times standard and projection switches only 1.5 times the standard work. These numbers are not qualitatively different from 1.99 and 1.63, but the apparent anomaly of logic level arrangement B is eliminated. When the work required for each logic level is calculated for the two hardware types, it becomes obvious that, for this task, the projection switches required a lower level of work (Figure 23).

b. Communication Changes Completed Under Failed Conditions

Analysis of the communication changes completed during failed conditions also indicated that pilot performance significantly differed depending on the MFK hardware type used (F = 4.69, df = 8, 17, $p < .01$). A stepwise discriminant analysis identified keyboard operation time (F = 16.94, df = 1, 142, $p < .01$; Figure 24) and altitude AAE (F = 4.43, df = 1, 141, $p < .05$, Figure 25) as the performance measures most sensitive to MFK hardware type differences.



*This logic level arrangement is classified according to which panel was front mounted and used for all but the first switch hit during failed conditions.

Figure 23. Work Factor for Each MFK Hardware Type as a Function of Logic Level Arrangement.

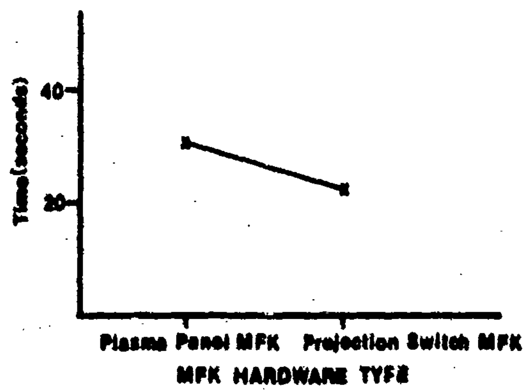


Figure 24. Mean Keyboard Operation Time During Failed Conditions with Each MFK Hardware Type

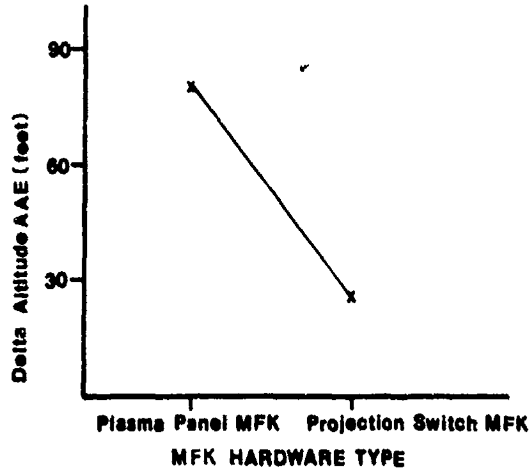


Figure 25. Delta Altitude AAE for Each MFK Hardware Type During Communication Changes Completed Under Failed Conditions

Mean time for projection switch operation was 22.0 seconds, compared with 30.6 seconds for the plasma panel. Altitude AAE was 24.7 feet for projection switches and 80.2 feet for the plasma panel. Both measures showed better performance with the projection switches.

Using the work factors derived as described in Appendix G, the plasma panel required 0.71 times the standard while the projection switches required only 0.55 times the standard.

c. Navigation Updates Completed Under Normal Conditions

The analysis of the navigation updates completed during normal conditions revealed that performance was significantly different depending upon which type of MFK hardware was used ($F = 4.08$, $df = 8, 17$, $p < .01$). The results of a stepwise discriminant analysis of this data showed that bank AAE ($F = 7.25$, $df = 1, 142$, $p < .01$) and bank RMS ($F = 3.43$, $df = 1, 141$, $p < .10$) were the dependent variables most sensitive to the type of hardware used. Inspection of Figure 26 illustrating bank AAE and RMS for each keyboard type indicates that the

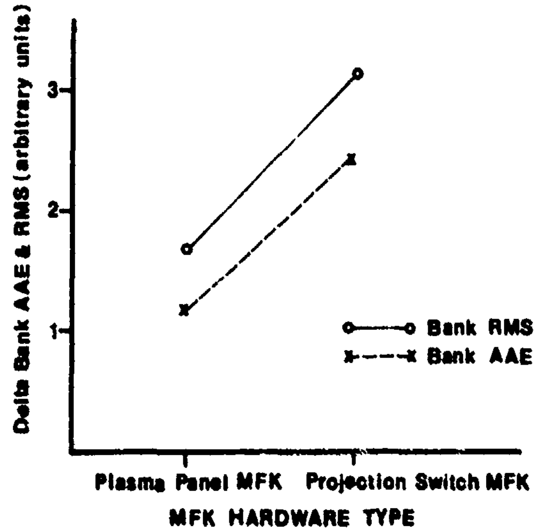


Figure 26. Delta Bank AAE and RMS for Each MFK Hardware Type During Navigation Updates Completed Under Normal Conditions

pilots had greater difficulty maintaining bank while completing navigation updates when the projection switches were on the front instrument panel as compared to performance with the plasma panel on the front instrument panel. In other words, in contrast with both failed condition tasks, pilot performance was better using the plasma panel when completing navigation updates under normal conditions.

While the work factors confirm better performance with the plasma panel (1.49 vs. 1.54), the difference was small.

d. Communication Changes Completed Under Normal Conditions

The MANOVA of communication changes completed under normal conditions revealed a significant MFK hardware type by control stick location interaction ($\underline{F}$ = 3.21, $\underline{df}$ = 8, 17, $\underline{p}$ < .05). A stepwise discriminant analysis identified keyboard operation time as the dependent variable most sensitive to these factors ($\underline{F}$ = 3.25, $\underline{df}$ = 3, 140, $\underline{p}$ < .05; Figure 27). The plasma panel/center stick configuration resulted in the worst performance by the pilots (23.6 seconds). When compared to this worst

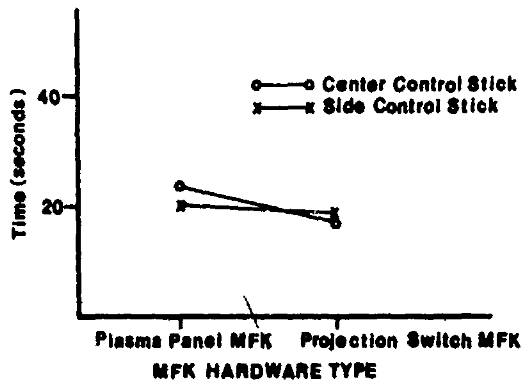


Figure 27. Mean Keyboard Operation Time with Each Control Stick Location as a Function of MFK Hardware Type

case configuration, keyboard operation time was significantly faster with the projection switches, for both center stick (17.8 seconds; $F = 8.87$, df = 1, 140, $p < .01$) and side stick (19.2 seconds; $F = 5.09$, $df = 1, 140$, $p < .05$) location. No other significant differences were found with other comparisons.

With a center stick, the work factors verified the superior performance of the projection switches versus the plasma panel (0.45 vs. 0.63). The finding that there was only a small difference between the hardware types when a side stick was used (0.57 and 0.51), tends to support the above results that the difference between these two are not significant.

e. MFK Hardware Type: Summary

In brief, analyses of both communication changes and navigation updates during failed conditions indicated that pilot performance was better on the right console MFK with the projection switches than with the plasma panel. Specifically, keyboard time and altitude AAE measures were better for communication changes completed during failed conditions in that time was less and errors smaller with the projection switches in comparison to the plasma panel. Keyboard operation time was also generally faster with the projection switches than with the plasma panel hardware for the navigation updates completed during failed conditions. The results further suggested that performance was degraded whenever the digits were entered on the plasma panel keyboard.

The analysis of communication changes completed under normal conditions using the front instrument panel MFK also indicated that pilot performance was better in terms of keyboard operation time with the projection switches than with the plasma panel. In contrast, the analysis of navigation updates completed under normal conditions using the front instrument panel MFK showed that performance was better in terms of keyboard operation time and maintaining bank with the plasma panel than with the projection switches.

2. LOGIC LEVEL ARRANGEMENT

a. Navigation Updates Completed Under Failed Conditions

Initial analysis revealed a significant main effect of logic level arrangement ($\underline{F} = 2.18$, $\underline{df} = 24, 49.91$, $\underline{p} < .05$). The stepwise discriminant analysis indicated that the time variable was most sensitive to the main effect ($\underline{F} = 2.96$, $\underline{df} = 3, 140$, $\underline{p} < .05$). Performance was significantly worse with logic level arrangement A (78.3 seconds) than that for arrangements C (59.1 seconds) and D (59.9 seconds; $\underline{p} < .05$). Additionally, although not statistically significant, performance was somewhat worse with logic level arrangement B (74.5 seconds) than that for arrangements C and D ($\underline{p} < .10$). These performance differences, however, should be examined in light of the significant interaction discussed below.

As mentioned earlier, a significant interaction of logic level arrangement and MFK hardware type was found in the MANOVA conducted on the navigation updates completed during failed conditions ($\underline{p} < .01$). An interaction of these factors indicates that the optimal logic level arrangement was determined by whether the pilot used the plasma panel or the projection switches. The results of a stepwise discriminant function analysis indicated that keyboard operation time was the dependent variable most sensitive to these factors (see Table 2 for F matrix). The mean time required for completion of a navigation update with each MFK hardware type is illustrated in Figure 28 as a function of logic level arrangement. As can be seen in the figure, performance was worse when pilots were using logic level arrangement A on the plasma panel. Examination of Table 2 indicates that this decrement in performance was significant at the .01 level for all configurations except for the projection switches/logic level arrangement B configuration, in which case there was only a marginal statistical difference ($p < .25$). The discriminant function analysis also indicated that keyboard operation was significantly worse using logic level arrangement B, with the projection switches located on the right console than performance with arrangements A ($p < .05$), C ($p < .01$), and D ($p < .05$) with the same MFK hardware. Further inspection of Figures 28 and 8 shows that keyboard operation time was greater when the digits were entered on the plasma panel and least when the separate, dedicated Digit/Mode Panel was used for digit entry (arrangements C and D).

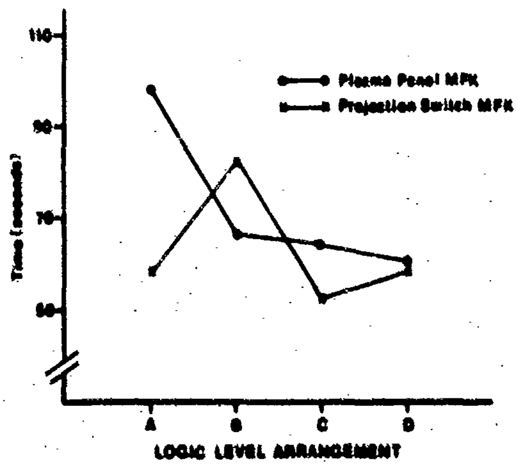


Figure 28. Mean Keyboard Operation Time with Each MFK Hardware Type as a Function of Logic Level Arrangement

TABLE 2

F MATRIX RESULTS OF STEPWISE DISCRIMINANT FUNCTION ANALYSIS ON KEYBOARD OPERATION TIME

F MATRIX - DEGREES OF FREEDOM (1,136)

	PLASMA PANEL MFK				PROJECTION SWITCH TYPE MFK		
	LLA	LLB	LLC	LLD	LLA	LLB	LLC
Plasma Panel							
LLB	8.52**						
LLC	8.88**	< 1					
LLD	11.34**	< 1	< 1				
Proj. Switches							
LLA	13.30**	< 1	< 1	< 1			
LLB	2.03°	2.23°	2.42°	3.77x	4.93*		
LLC	17.36**	1.56°	1.41°	< 1	< 1	7.51**	
LLD	13.14**	< 1	< 1	< 1	< 1	4.84*	< 1

**p <.01   xp <.10

*p <.05   °p <.25

LL = Logic Level

The work analysis supported the superiority of logic level arrangements C (work factor = 1.55) and D (1.66) over A (2.11) and B (1.92). When the hardware effect was taken into consideration, the smallest work factor using plasma panel (with a work factor of 1.79) was larger than the largest work factor using the projection switches (1.68). Logic level arrangement C was superior, regardless of whether plasma panel (1.70) or projection switches (1.31) were used.

b. Communication Changes Completed Under Failed Conditions

Significant performance difference among logic level arrangements were found in the MANOVA of the communication changes completed during failed conditions ($\underline{F}$ = 1.92, $\underline{df}$ = 24, 49.91, $\underline{p}$ < .05) The results of the stepwise discriminant analysis identified altitude AAE as the dependent variable most sensitive to these differences ($\underline{F}$ = 2.51, $\underline{df}$ = 3, 140, $\underline{p}$ < .10; Figure 29). Although the difference was not statistically significant, the results are in agreement with those obtained during navigation tasks under failed conditions. Pilot performance was significantly worse with logic level arrangement B (86.7 ft) than for arrangements C (24.5 ft) and D (34.1 ft; $\underline{p}$ < .05). Furthermore, although not statistically significant, performance with arrangement A (64.8 ft) was worse than C and D at the .25 level, thereby, indicating the same trend. Namely, that logic level arrangements C and D involved the use of the dedicated Digit/Mode Panel on the left console for entering digits, whereas, logic level arrangements A and B required the use of the MFK for digit entry (Figure 8).

The work equation confirmed these results. Arrangements C and D were essentially the same (work factor = 0.60). Arrangement B was the most difficult (0.72). Arrangement A had an intermediate work factor 0.63.

c. MFK Operation Under Normal Conditions

MANOVAs of communication changes and navigation updates completed during normal conditions indicated there were no significant differences

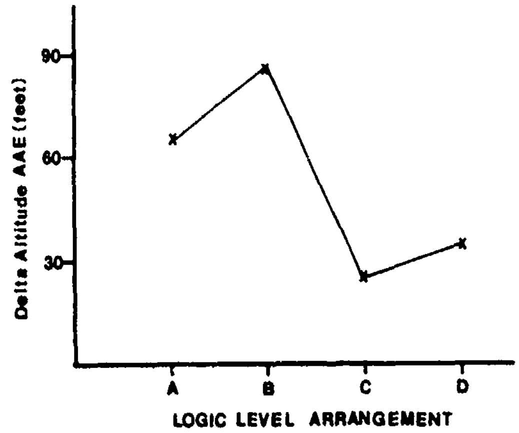


Figure 29. Delta Altitude AAE for Each Logic Level Arrangement During Communication Changes Completed Under Failed Conditions

among the four logic level arrangements. In other words, during normal conditions, pilot performance was essentially the same regardless of the particular logic level arrangement (A, B, C, or D) used to complete the keyboard operations.

d. Logic Level Arrangement: Summary

To summarize, the analyses of keyboard operations completed under normal conditions did not reveal performance differences among logic level arrangements, whereas those for failed conditions did. Performance was generally worse when the digits were entered on the plasma panel and best when the separate, dedicated Digit/Mode Panel was used for digit entry. Two cases are noteworthy. In the first case, for the analysis of navigation updates completed on the right console MFK under failed conditions, keyboard operation was slower with logic level arrangement A using the plasma panel on the right console than any other keyboard/logic level arrangement configuration. In the second case, keyboard operation was slower with logic level arrangement B using the projection switches on the right console than that for arrangements A, C, and D with the same keyboard on the right console. In both of these cases, the logic level arrangements were such that the digits were entered on the plasma panel type MFK. In a separate analysis of communication changes completed under failed conditions, similar results were found indicating that performance was worse in terms of maintaining altitude with logic level arrangements A and B than for C and D.

3. CONTROL STICK LOCATION

a. MFK Operation Under Failed Conditions

Analyses of navigation updates and communication changes completed under failed conditions did not indicate any significant differences due to control stick location. In other words, pilot performance during failed conditions was essentially the same regardless of where the control stick was located.

b. Navigation Updates Completed Under Normal Conditions

No significant differences due to control stick location were found in the analysis of navigation updates completed under normal conditions.

c. Communication Changes Completed Under Normal Conditions

As mentioned in Section IV-1.d, a significant interaction of control stick location and MFK hardware type was found in the MANOVA conducted on the communication changes completed under normal conditions ($\underline{p} < .05$). An interaction of these factors indicates that the optimal control stick location during normal communication changes was determined by whether the pilot used the plasma panel or projection switches on the front panel. A stepwise discriminant function analysis identified time as the dependent variable most sensitive to these factors ($\underline{p} < .05$). Referring to Figure 27, there was a significant difference in time between the center stick/plasma panel configuration and both configurations using the projection switches (center stick/projection switches, $\underline{p} < .01$; side stick/projection switches, $\underline{p} < .05$).

d. Control Stick Location: Summary

Analyses of communication and navigation keyboard operations under failed conditions and analysis of navigation updates completed under normal conditions failed to reveal significant differences due to control stick location. The analysis of communication changes completed under normal conditions, however, indicated that it took more time to complete tasks on the plasma panel MFK than on the projection switch type MFK regardless of which control stick location was used. Performance was especially degraded with the center stick/plasma panel configuration.

SECTION V

DISCUSSION

In this section, the results reported in Section IV are discussed. For simplicity, the same presentation order of topics and findings is used. Findings are interpreted and explanations suggested for:

a. MFK hardware type

b. Logic level arrangement

c. Control stick location

When applicable, the subjective responses of the participating pilots are referenced.

1. MFK HARDWARE TYPE

A projection switch type MFK was compared with a plasma panel MFK. Both MFKs were examined under failed conditions (right console) and under normal conditions (front panel) for communication changes, as well as navigation updates.

In addition to the basic physical difference between the plasma and projection hardware, there were design differences between the two hardware implementations. In particular, problems were noted with the plasma panel MFK due to the following design features:

1. The white tape lines radiating between legends and switches on the plasma panel were not parallel because the switches took more space than the legends.

2. The switches on the plasma panel were smaller and mounted closer together than the switches used on the projection switch MFK.

3. The dimensions of the plasma panel surface caused the two columns of switches to be nearly a foot apart. This physical separation of the two columns of switches made the operation of the switches on

the right hand side of the panel more difficult, especially when mounted on the right console.

4. Parallax problems resulted when the plasma panel was on the right console due to the fact that the switches on the plasma panel were not flush-mounted, and the panel was not mounted at the optimal viewing angle.

It is important to note that these ancillary design differences could, by themselves, account for any "hardware" differences found in the analyses. Care must be taken not to generalize any specific findings for these MFK configurations to other plasma panels or projection switches at other cockpit locations.

a. MFK Operation Under Failed Conditions

Under failed conditions, there is no doubt about the results with respect to hardware type: the projection switch panel used in this study was better than the plasma panel used. Pilot performance was better for projection switches, regardless of task difficulty. (The navigation task with 19 switch hits was considered to be more difficult that the communication task with 8 switch hits.) Both tasks took longer when the plasma panel was used. Aircraft control parameters (bank and altitude AAE) showed that pilot performance on the flying task deteriorated when the plasma panel was used. Seven of the nine pilots stated that, during failed conditions the projection switches were much easier to operate. Some pilots commented that the legends on the lighted projection switches made selection of the appropriate switch much faster. Concerning the plasma panel, the pilots commented that operation was difficult due to the parallax problems, radiating lines, small switch size, and switch arrangement.

b. MFK Operations Under Normal Conditions

The analyses of the results from the MFK operations on the front panel are conflicting. Subjective data indicated that the pilots felt that the projection switches were easier to operate (six of the nine said "much easier"). The performance analyses supported this conclusion for the communication changes. However, unlike the findings for the normal communication changes (projection switches better), the performance for navigation updates completed under normal conditions showed the plasma panel MFK to be better.

Examination of the design differences between the two MFKs suggests possible explanations for these findings. First, it should be noted that since normal operation involved the use of the front panel location, parallax problems associated with the mounting angle on the right console were reduced for both the communication changes and navigation updates. Secondly, the separated columns on the plasma panel were more of a detrimental factor during communication changes compared to navigation updates. For example, the communication changes executed on the plasma panel required as many as three-fourths of the total switch hits on the right side of the MFK. Since most pilots operated the switches with the left hand while flying with the right, reaching the switches on the right side of the panel was difficult, especially when a center stick was used. This problem, combined with the fact that the MFK operation during communication changes involved alternating between the left and right sides of the separated columns, tended to make plasma panel operation more difficult. Thus, even though parallax was not a problem during completion of communication changes on the plasma panel during normal conditions, three of the four design deficiencies (radiating lines, small switch size, and separated columns) still affected performance. It is suggested that, for this reason, the results of the normal communication changes were in agreement with those obtained under the failed conditions (i.e., projection switch better). Regarding the navigation updates, however, the negative effects of both parallax and separated columns were reduced. For updates, less than one-third of the normal navigation switch hits required the use of switches on the right side of the plasma panel. By using mainly the switches on the left side of the panel, the effect of widely separated columns was reduced. It is possible that the reduction of these effects, in this case, accounts for the fact that plasma panel operation was found easier than projection switch operation. At the very least, these findings cast some doubt on any attempt to generalize conclusions about the hardware types and indicate that further investigation is necessary.

Another possible explanation for the better performance with the plasma panel during normal navigation updates is that the more optimally designed projection switch logic encouraged the subjects to work faster and devote more attention to keyboard operation. This apparently caused the pilot to ignore the flying task, as shown by the performance decrement in maintaining bank, during failed navigation updates. However, considering the difficulty of navigation updates, this could result in the pilots making more errors in the keyboard task. In fact, pilots did accomplish the navigation tasks faster using the projection switches (52.5 seconds vs. 56.1 seconds) and had a higher error rate using the projection switches (1.12 vs. 1.10). The trends shown by these results, while not significant, do tend to support this explanation.

The data also suggests that the pilots devoted more attention to keyboard operation during normal communication changes completed on the projection switches. Since fewer switch hits were required for the communication changes compared to the navigation updates, it appears that the pilots who devoted full attention to projection switch operation were able to complete the task before flying task errors developed, and were able to complete the keyboard task with fewer errors. Both attitude and bank errors were less with the projection switches than the plasma panel. In addition, operation with the projection switches MFK was faster (18.51 vs. 22.14 sec) and had a lower error rate (1.03 vs. 1.08) compared to the plasma panel. The trends shown by these results do tend to support this explanation. Conclusive evidence is not available, but could be obtained by further experiments with optimized design of the candidate panels.

2. LOGIC LEVEL ARRANGEMENT

Four logic level arrangements were evaluated. They involved changes in the location of switches used for steps in the operating sequence (see Figure 8).

a. MFK Operations Under Failed Conditions

During operations under failed conditions (increased task difficulty), the advantages of a separate Digit/Mode Keyboard for logic levels 1 and/or 4, whether due to the dedicated switches or optimized number arrangement, is apparent as shown by the significantly better pilot performance under logic level arrangements C and D. Contrary to these findings, the subjective data indicated that the pilots preferred logic level arrangement B. This was apparently due to the fact that only one switch hit was required on the right console MFK. All other switch hits in logic level arrangement B were on the front panel MFK. When considering only the logic level arrangements where the front panel was failed, the pilots preferred arrangement C. The pilots unanimously agreed that operation of the MFK was very inefficient with arrangement A which required the use of the MFK for digit entry. This latter finding, in conjunction with the results of the performance analyses, suggests that logic level arrangements which use locations that are hard to see and reach, such as the vertical mounting on the right console, should be avoided.

b. MFK Operations Under Normal Conditions

A most noteworthy result concerning logic level arrangement was the failure to find any significant differences during normal operation. This implies that, as long as the panels are readable and reachable with no control stick interference, the distribution of logic levels among panels does not affect pilot performance. Performance trends showed that logic level arrangements C and D which involved digit entry on the separate, dedicated Digit/Mode Panel tended to be better than arrangements A and B which required the use of the MFK for digit entry. Subjective data indicated that for normal operation, pilots preferred arrangement D which involved operation of the front panel MFK for the first three logic level steps and the Digit/Mode Panel for the fourth.

3. CONTROL STICK LOCATION

The use of both a center and side control stick location was examined during the experiment. It was not the intent of the study to evaluate differences in stick location but rather the effects of stick location on MFK operation.

a. MFK Operations Under Failed Conditions

Concerning operation of the right console MFK with the side control stick, eight out of nine pilots responded that interference problems occurred with this configuration. The pilots also indicated that slightly less interference resulted when the center stick location was used with the right console MFK. Some commented that this configuration made it possible to fly with the left hand and operate the keyboard with the right. Note, however, that contrary to the pilots' responses on the questionnaire, performance analyses did not indicate any significant findings in respect to the control stick location with the right console MFK.

b. MFK Operations Under Normal Conditions

The results of the analyses of the front panel MFK operation during normal conditions revealed effects due to control stick location for communication changes but not for navigation updates. The analyses indicated that when the right side switches of the plasma panel were obstructed by the center stick during the normal communication changes, operation was degraded. It is suggested that this control stick effect occurred in the communication changes as opposed to the navigation updates because the UHF radio changes involved more operation of the switches on the right side including the "A/N" button in the lower right corner of the plasma panel. Even though the performance analyses showed interference between the center stick and the plasma panel, only two pilots indicated on the questionnaire that the center stick interferred with the front panel. Eight out of nine pilots did state, however, that the side stick location aided the operation of the front panel MFK and some further commented that this configuration allowed full unobstructed view of the front panel. This suggests that the center stick location obstructed the view of the front panel.

From these analyses, it can be concluded that, so long as MFK operation is not directly inhibited by the location of the control stick, performance is not affected. In other words, by proper location of the MFK, its operation is compatible with the control stick in either the center or right side position.

SECTION VI

CONCLUSIONS

As a result of this evaluation on the use of multifunction keyboards (MFKs) in single-seat Air Force cockpits, the following conclusions can be made:

(1) Progressing through the four levels of system control was effective. The overall time required for pilots to complete communication changes and navigation updates, during simulated flight was around 20 seconds and 55 seconds, respectively.

(2) Operations other than digit entry should be consolidated on a single keyboard.

(3) The digit entry should be completed on a separate dedicated panel.

(4) The location of the control stick (center or side) does not affect performance as long as MFK operation is not physically inhibited by the stick.

(5) Plasma panel type keyboards should be designed such that the legends on the panel are directly adjacent and in line with the corresponding switches.

(6) The viewing angle of keyboards is an important factor in keyboard operation. This is especially critical when the switches are not flush-mounted with the panel.

(7) The switches should be located on the keyboard such that hand movements alternating between the left and right sides of the panel are minimized.

APPENDIX A

COCKPIT DISPLAYS

Four electro-optical displays were used in the present study to provide information for utilization by the pilot (Figure 9). The following describes each display in detail:

a. Vertical Situation Display (VSD)

A nine inch diagonal color monitor presented flight symbology to the pilot. The symbology consisted of (1) a white horizon line delineating the boundary between a blue sky and brown earth background, (2) a white pitch ladder with 5 degree increments for the first ± 30 degrees from the horizon line and ten degrees thereafter, (3) black roll indexes every ten degrees (± 60 degrees) with a white roll index marker. (4) a flight director symbol (active in bank only) in orange, and (5) a fixed black aircraft symbol. Altitude, indicated airspeed, heading, vertical velocity, and acceleration (g's) were presented digitally in white on black background. In addition, trend information for the airspeed and altitude parameters was provided by white thermometer type bars which were placed above the respective digital readouts. (See Figure 16 for a representation.)

b. Horizontal Situation Display (HSD)

A nine inch diagonal monochrome monitor presented simplified navigation information in a heading up format. The symbology consisted of (1) a triangular aircraft symbol, (2) a symbolic flight path between mission waypoints, and (3) digital readouts of ground speed, heading, and distance to the next waypoint. All symbology was green on a black background. In addition, the line representing the flight path became jagged or stairstepped when the aircraft's heading did not parallel the flight path. (See Figure 17.)

c. Multipurpose Displays (MPDs)

Two five inch monochrome monitors were used. The one mounted on the left side of the cockpit provided either communication data or navigation data (Figures 18 and 19). Engine instrumentation and keyboard failure status information was displayed on the right MPD (Figures 20 and 21). This MPD had sixteen peripheral push button switches. However, for the present study, these switches remained inoperable.

APPENDIX B

EXPERIMENTER'S CONSOLE AND SIMULATOR FACILITIES

1. EXPERIMENTER'S CONSOLE

The console's four, six inch diagonal, monochrome CRT displays, provided the experimenter with the capacity of monitoring the simulator displays (VSD, HSD, and 2 MPDs). The experimenter was also able to initiate tasks and control the normal/failure status of the configurations. In order to minimize experimenter workload, cockpit reconfiguration was automated as much as possible and incorrect waypoint and frequency digits were detected by the computer.

2. SIMULATOR FACILITIES

The simulator consisted of four interconnected facilities as shown in Figure B1. A functional description of each system element is provided below.

a. PDP 11/45

Configuration Control - used to set up the cockpit controls/displays configuration prior to each flight.

Display Assembly - generated image listings to be further processed by the Ramtek raster symbol generator. Data from the simulation models was used for the VSD and MPD formats.

Map Driver - provided output control of map data to the Ramtek symbol generator. The image lists of the map were done by the DEC 10.

Keyboard Logic - processed incoming switch data and determined the display state of all the keyboards.

Flight Control Sampling and Scaling - buffered and scaled flight control data to be used by the DEC 10 simulation models.

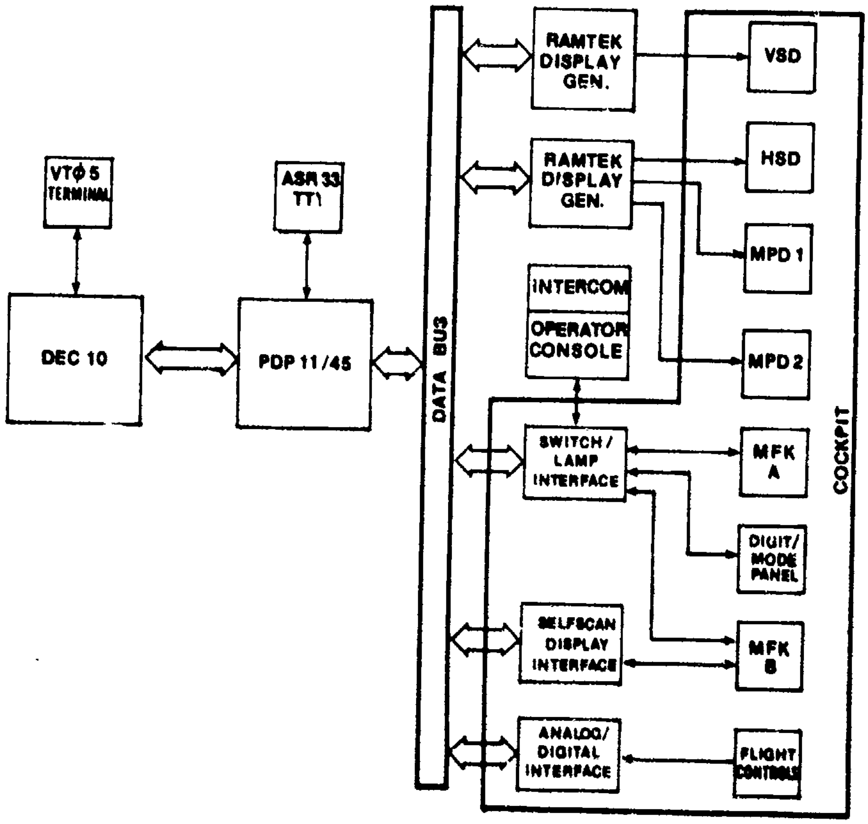


Figure B1. System Hardware Block Diagram

b. DEC 10

Simulation Models - provided all necessary aircraft parameters to the 11/45 to be used in display processing.

Map Assembly - generated a display list of symbolic waypoint map information to be processed by the Ramtek symbol generator.

Data Recording - recorded cockpit display parameter data on magnetic tape at a 20 per second iteration rate.

Data Reduction - an off-line program reduced the raw real-time recorded data into meaningful data that can be analyzed.

c. Ramtek

Display Generation - Processed image lists to display VSD, HSD, and MPDs on 525 line raster monitors.

d. Cockpit

Keyboard Input/Output - provided a switch image buffer of all cockpit switch states to be sampled by the 11/45. Also decoded keyboard display data being sent from the 11/45.

Flight Control - Digitized analog stick, rudder, and thrust control inputs and buffered the resultant data for transmission to the 11/45.

APPENDIX C

DAILY TEST SCHEDULES

The following daily test schedules (Tables C1 through C3) indicate the time and activity to train, test, and debrief two pilots during six consecutive days of the experiment. Alternate schedules were also available for training a pilot and testing a pilot in one day, testing a pilot and debriefing a pilot in one day, etc. Times for controls/displays familiarization, training flights, test flights, and simulator reconfigurations are indicated in the schedules provided.

TABLE 31

TEST SCHEDULE FOR TRAINING TWO PILOTS

Day 1

Time	Activity
1245 - 1315	Introduction to Simulation, Facility, and Purpose of Study/Pilot A
1315 - 1345	Familiarization with simulator/Pilot A
1345 - 1355	Practice Trial 1/Pilot A
1355 - 1405	Software change
1405 - 1415	Practice Trial 2/Pilot A
1415 - 1425	Software change
1425 - 1435	Practice Trial 3/Pilot A
1435 - 1445	Software change
1445 - 1455	Practice Trial 4/Pilot A
1455 - 1500	Software change/control stick change
1500 - 1515	Introduction to Simulation/Pilot B
1515 - 1545	Familiarization with Simulator/Pilot B
1545 - 1555	Practice Trial 1/Pilot B
1555 - 1605	Software change
1605 - 1615	Practice Trial 2/Pilot B
1615 - 1625	Software change
1625 - 1635	Practice Trial 3/Pilot B
1635 - 1645	Software change
1645 - 1655	Practice Trial 4/Pilot B

Computer time = 220 minutes for eight practice runs.

TABLE C2

TEST SCHEDULE FOR TESTING TWO PILOTS

Days 2-5

Time	Activity
1300 - 1310	Trial 1/Pilot A
1310 - 1320	Software change
1320 - 1330	Trial 2/Pilot A
1330 - 1340	Software change
1340 - 1350	Trial 3/Pilot A
1350 - 1400	Software change
1400 - 1410	Trial 4/Pilot A
1410 - 1420	Software change
1420 - 1430	Trial 5/Pilot A
1430 - 1450	Software change/control stick change
1450 - 1500	Trial 1/Pilot B
1500 - 1510	Software change
1510 - 1520	Trial 2/Pilot B
1520 - 1530	Software change
1530 - 1540	Trial 3/Pilot B
1540 - 1550	Software change
1550 - 1600	Trial 4/Pilot B
1600 - 1610	Software change
1610 - 1620	Trial 5/Pilot B

Computer time per day = 200 minutes for 10 test runs.

TABLE C3

TEST SCHEDULE FOR TESTING AND DEBRIEFING TWO PILOTS

Day 6

Time	Activity
1300 - 1310	Trial 1/Pilot A
1310 - 1320	Software change
1320 - 1330	Trial 2/Pilot A
1330 - 1340	Software change
1340 - 1350	Trial 3/Pilot A
1350 - 1400	Software change
1400 - 1410	Trial 4/Pilot A
1410 - 1430	Software change/control stick change
	Debrief Pilot A
1430 - 1440	Trial 1/Pilot B
1440 - 1450	Software change
1450 - 1500	Trial 2/Pilot B
1500 - 1510	Software change
1510 - 1520	Trial 3/Pilot B
1520 - 1530	Software change
1530 - 1540	Trial 4/Pilot B
1540 - 1640	Debrief Pilot B

Computer Time = 160 minutes for eight test runs.

APPENDIX D

FLIGHT INFORMATION

A total of six missions, four for test flights and two for training flights, were used in the experiment. Initial conditions for all the missions are specified in Table D1. The programmed track for each mission was 70 nm with a turn of approximately 90 degrees at waypoint 2. At 420 knots ground speed, the total flight segment lasted for ten minutes. The flight, however, was terminated at the completion of the fourth task, even if the pilot did not reach the end of the track. Figure D1 shows a sample AF Form 70 which was given to the pilot prior to each flight. The forms provided information pertaining to radio frequencies and waypoint coordinates for use during the secondary tasks.

TABLE D1

INITIAL CONDITIONS FOR FLIGHT MISSIONS

Training Flight 1.

Altitude	-	20,000'
Ground Speed	-	420 knots
Heading	-	165°
Location	-	144825 N
		1065045 E

Training Flight 2.

Altitude	-	20,000'
Ground Speed	-	420 knots
Heading	-	288°
Location	-	141104 N
		1074040 E

Test Flight 1.

Altitude	-	20,000'
Ground Speed	-	420 knots
Heading	-	263°
Location	-	150730 N
		1083815 E

Test Flight 2.

Altitude	-	20,000'
Ground Speed	-	420 knots
Heading	-	188°
Location	-	154720 N
		1081459 E

Test Flight 3.

Altitude	-	20,000'
Ground Speed	-	420 knots
Heading	-	178°
Location	-	161330 N
		1080540 E

Test Flight 4.

Altitude	-	20,000'
Ground Speed	-	420 knots
Heading	-	270°
Location	-	153435 N
		1083605 E

PILOT'S FLIGHT PLAN AND FLIGHT LOG

ARTC FREQ					
	A 241.4	D 282.1	G 288.2	J 398.1	M 226.2
	B 257.3	E 395.0	H 331.0	K 284.2	N 317.4
	C 335.1	F 255.6	I 234.8	L 244.8	O 340.7

AIRCRAFT IDENT	TAKE-OFF TIME	TOTAL DISTANCE	TOTAL ETE	TOTAL AMT FUEL
AGARD 183				9800

FIX	ROUTE	IDENT / FREQ	IDENT / FREQ	MAG CRS	DISTANCE / REMAIN	GROUND SPEED	ETE / REMAIN	ETA / ATA	LEG / REMAIN	ACTUAL FUEL REMAIN
N150504		ALLEYCAT		263	24	420	3:27		1800	
E1081324									8000	
N154734		NAIL		008	46	420	6:34		3200	
E1081553									4800	

AF FORM MAY 66 70 REPLACES AF FORM 21A, JAN 63, WHICH WILL BE USED UNTIL STOCK IS EXHAUSTED.

Figure D-1. Sample AF Form 70

APPENDIX E

PILOT QUESTIONNAIRES

The pilot data questionnaire form concerning background flying experience was completed by each pilot subject sometime during the experiment. Following the simulation, the pilots' filled out a Likert-type rating questionnaire designed to elicit subjective evaluations concerning each of the four logic level arrangements, the location of the control stick, MFK type and location, and display formats. The copy of the debriefing questionnaire included in this appendix also provides the pilots' responses.

PILOT DATA

Date: ______________

Name: ____

Rank: ______________ SN: ______________

Present Duty Assignment: ______________________________

Organization ______________________________________

Symbol: ______________ Extension: ______________

Total Active Duty: ______________ Age: ______

Date Pilot Rating Obtained ______________________________

Total Flying Hours ______________ Total Jet ______________

Hours in A/C by Type: ______________

____

____

____

Height: ______________ Weight: ______________

PILOT DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to find out what you think about this cockpit. It is not a test and you may take as long as you need.

Your candid opinions will help in the evaluation of this cockpit. Please answer all the questions by indicating the response which most nearly describes your feelings. When a question reminds you of some particular comment, or when you want to explain your answer, feel free to write your feelings in the extra space provided.

The questionnaire is divided into three sections representing the specific areas of interest at this time. The first section deals primarily with each of the four logic level arrangements between the primary and backup keyboards. The second section is concerned with the location of the control stick and keyboard type, while the third section deals with the formats used on other displays.

SECTION I

KEYBOARD LOGIC LEVEL ARRANGEMENT

You may have noticed that each new plane you fly has more and more control panels, and that you need to make like a pretzel to reach some of them.

Operations specialists tell us we need more sophisticated sub-systems.

Avionics experts tell us each system needs a separate control panel.

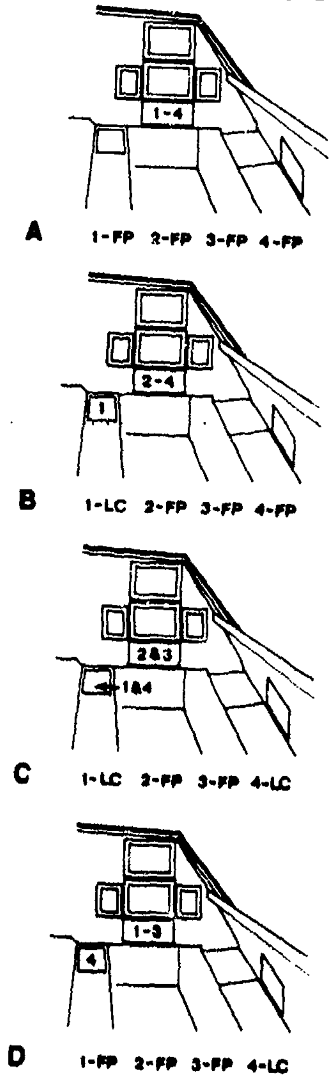
Pilots tell us that there are already too many switches, knobs, dials, and warning lights.

One solution is to design a Multifunction Keyboard (MFK) that will allow the pilot to control several sub-systems with a single panel. Catch 22: if this single panel fails (and you know who will be flying the plane in what kind of weather when it does) all those sub-systems (COMM, NAV, WEAPONS, IFF, etc.) fail with it. Engineers call this a degraded mode. A solution to this problem is to put a backup keyboard in the cockpit.

The systems being studied here have four step procedures which we call logic levels. When a panel fails, the logic levels are <u>automatically</u> redistributed to other panels. Figure A shows four different distributions of the four logic levels which are used for "normal" operation in the present experiment. Figure B shows alternate distributions of the four logic levels for "failure" or "degraded" operation.

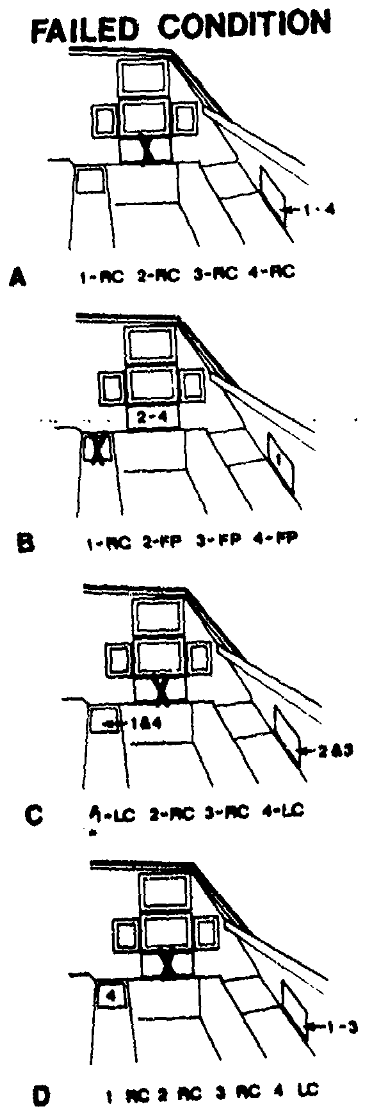
Answer the following questions in this manner: for each question, put the number of the response corresponding to your feelings under the letter representing the appropriate logic level arrangement. Please identify any comments you make with the appropriate logic level arrangement letter.

NORMAL CONDITION



FP = Front Panel
LC = Left Console
RC = Right Console

Figure A. Keyboard operation for each logic level arrangement during normal conditions.



FP = Front Panel
LC = Left Console
RC = Right Console

Figure 8. Keyboard operation for each logic level arrangement during failed conditions.

I-1. During <u>normal</u> operation, progressing through the four logic levels to enter data on the MFK was

		A	B	C	D
1.	Very inefficient				
2.	Moderately inefficient	2/9	1/9	3/9	
3.	Moderately efficient	4/9	7/9	3/9	5/9
4.	Very efficient	3/9	1/9	3/9	4/9

Comments:

- For example, changing radio frequency is easier with MFK method because presently with standard radios, you have to usually check the frequency after inserted. With the MFK you can punch in numbers by "touch" much as you would type by touch.

- It is easier and more efficient if the same keyboard can be used for all levels.

- I found the left console the most convenient to operate, particularly when putting in the waypoints. Its operation required the smallest physical movement from the manual position.

- Since the majority of comm tasks involve changing frequencies, isn't it possible to make that a 3 step or 2 step operation simply by using another key?

- Having steps 1-4 on the same panel is a plus. Using the left console would be the optimal for me.

I-2. Considering the overall mission workload during normal conditions, operation of the MFK

		A	B	C	D
1.	Interfered greatly with completion of other mission tasks				
2.	Interfered slightly with completion of other mission tasks	4/9	2/9	4/9	1/9
3.	Did not interfere with completion of other mission tasks	4/9	6/9	4/9	7/9
4.	Aided slightly with completion of other mission tasks	1/9	1/9	1/9	
5.	Aided greatly with completion of other mission tasks				1/9

Comments:

- The more tasks that were on the front panel, the more deviations I could pick up with my peripheral vision on the ADI.

I-3A. During failure operation, progressing through four logic levels to enter data on the MFK was

		A	B	C	D
1.	Very inefficient	9/9		3/9	6/9
2.	Moderately inefficient		4/9	6/9	3/9
3.	Moderately efficient		5/9		
4.	Very efficient				

Comments:

- Using the right hand panel was difficult. Turning the head to see the panel and then back to the ADI can cause vertigo.
- On the plasma panel, it was very difficult to determine which button corresponded to which function and made the process of completing a task much slower and more difficult.

I-3B. Suppose we put the backup keyboard at the right MPD location instead of on the right hand console. During failure operation, progressing through the four logic levels to enter data on the MFK would be

		A	B	C	D
1.	Very inefficient	1/9		2/9	2/9
2.	Moderately inefficient	5/9	2/9	4/9	5/9
3.	Moderately efficient	2/9	7/9	3/9	2/9
4.	Very efficient	1/9			

Comments:

- Having to reach with the left hand to the right hand side of the cockpit can cause problems. Use the left MPD instead.

- How about left MPD for convencience? Also depends on stick location.

- It is easier and more efficient if the same keyboard can be used for all levels.

- Right hand would already be occupied controlling aircraft with center and side stick. This would necessitate reaching cross cockpit with the left arm to operate MPD.

- Would probably be better with side stick, otherwise, I would prefer backup on left MPD location.

I-4. Considering the overall mission workload during failure conditions, operation of the MFK

		A	B	C	D
1.	Interfered greatly with completion of other mission tasks	9/9		3/9	7/9
2.	Interfered slightly with completion of other mission tasks		7/9	6/9	2/9
3.	Did not interfere with completion of other mission tasks		2/9		
4.	Aided slightly with completion of other mission tasks				
5.	Aided greatly with completion of other mission tasks				

Comments:

- Too much head shifting around in Logic Level C.
- Plasma panel bad.
- During a failure mode, why not switch all 4 steps to another MFK.
- Using the right hand panel was difficult. Turning the head to see the panel and then back to the ADI can cause vertigo.

For the following questions, fill in the circle which most nearly described your feelings about the object of the question. Space is provided for any additional comments you might have.

I-5. Concerning the arrangement of the four logic levels, keyboard operation is

Much easier on 2 MFKs compared to 1 MFK

1/9 Moderately easier on 2 MFKs compared to 1 MFK

3/9 Equally easy on 2 MFKs and 1 MFK

4/9 Moderately easier on 1 MFK compared to 2 MFKs

1/9 Much easier on 1 MFK compared to 2 MFKs

Comments:

- It all depends on the location of the keyboards.
- Depends more on arrangement and location than number.

I-6. The MFK should contain

More keys and more logic levels

2/9 More keys and fewer logic levels

4/9 The number of keys and logic levels as it now has

1/9 Fewer keys and more logic levels

2/9 Fewer keys and fewer logic levels

Comments:

- Since the majority of comm tasks involve changing frequencies, isn't it possible to make that a 3 step or 2 step operation simply by using another key?
- There is obvoiusly a minimum number possible.
- I don't want to have to do mental calculations (which logic level am I in) when things are going wrong in the weather.

I-7. The MPD pre-entry readout was

5/9 Very useful in detecting data input errors from the MFK

3/9 Slightly useful in detecting data input errors from the MFK

1/9 Not useful in detecting data input errors from the MFK

Comments:

- Absolutely essential.
- On navigation entries, it's a necessity.
- It might be of better use if readout number were bigger and/or brighter than other numbers.
- It was too cluttered with information. Printing needs to be larger and more prominent.

I-8. The control actions required to correct incorrect entries in the MFK were

3/9 Very easy to perform

2/9 Moderately easy to perform

2/9 Moderately difficult to perform

2/9 Very difficult to perform

Comments:

- Difficult especially on the navigation entry (where I made most errors). Especially if two panels were involved, I would forget where to back up to start over.
- Difficult in the sense that it required repeating the task almost from the beginning.
- You shouldn't have to clear the entire entry because you get the last digit wrong after entering 18 correctly.
- Kept forgetting level to which the system reverted with clear button.

- Very easy to perform but frustrating at times after making a mistake on the last number of a waypoint and then having to go through the whole series of tasks and number again. Maybe a back space design similar to the clear on the logic step could be developed so that if a mistake is made, you could back space and erase a number or numbers until your data is correct.

SECTION II

EFFECT OF CONTROL STICK LOCATION AND TYPE OF KEYBOARD ON KEYBOARD OPERATION

Both a center and a side stick location were used in the present experiment. The purpose of examining both locations is to determine if stick placement interferes with the operation of the multifunction keyboards. Another factor under consideration in this study concerns the relative ease of keyboard operation in respect to the type of keyboard, location of the keyboard, and characteristic switch size, legend, etc. The following section specifically addresses these considerations. As before, please fill in the appropriate circle which describes your feelings about each configuration and note any comments you might have. Figures C-E should be utilized when answering questions in this section.

II-1. The placement of the control stick in a center location

Interfered greatly with the operation of the front panel keyboard

2/9 Interfered slightly with the operation of the front panel keyboard

7/9 Did not interfere with the operation of the front panel keyboard

Aided slightly with the operation of the front panel keyboard

Aided greatly with the operation of the front panel keyboard

Comments:

- The placement of the control stick in a center location did not interfere with the operation of the front panel keyboard. In the 135, the column is always in the way so I didn't notice anything unusual. I just worked around it.

- Much easier to operate front panel when projection panel is in front, plasma panel keys too close to operate efficiently.

- The placement of the control stick in a center location interfered slightly with the operation of the front panel keyboard because one had to reach over the top of the stick to push the "A/N" button.

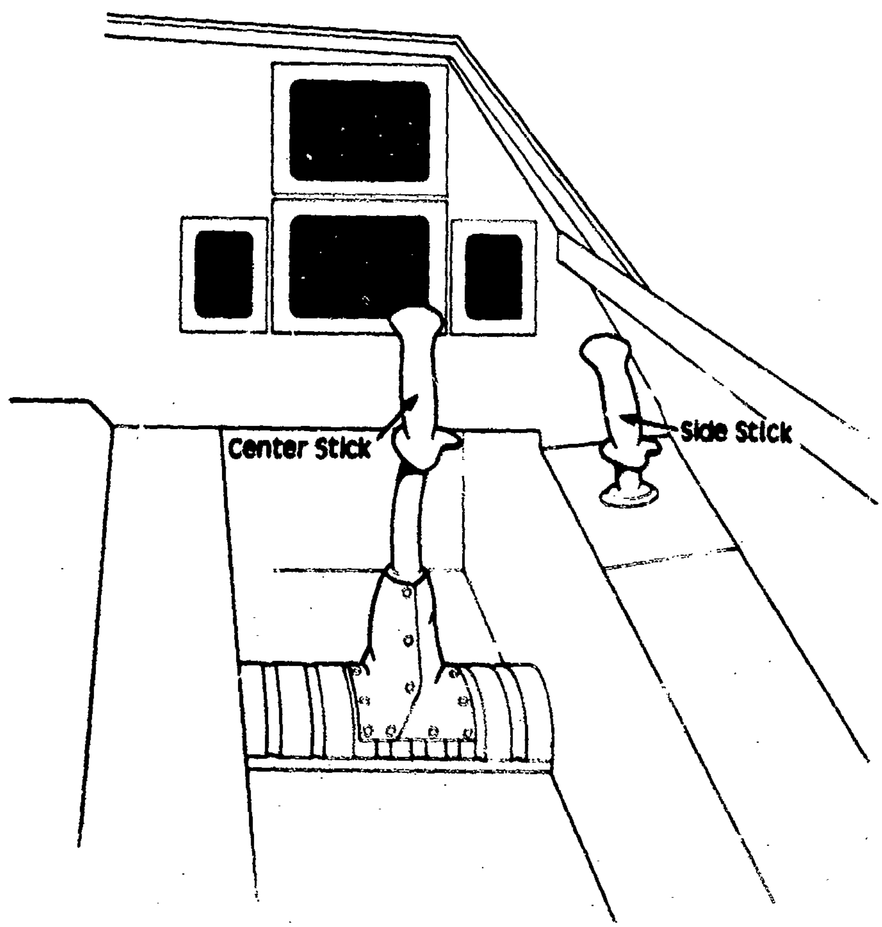


Figure C. Side and center locations of the control stick.

II-2. The placement of the <u>control stick</u> in a <u>center</u> location

2/9 Interfered greatly with the operation of the right hand console keyboard

4/9 Interfered slightly with the operation of the right hand console keyboard

Did not interfere with the operation of the right hand console keyboard

1/9 Aided slightly with the operation of the right hand console keyboard

2/9 Aided greatly with the operation of the right hand console

Comments:

- You are able to hold a much more stable flying platform with center stick when reaching across with left arm to operate right hand panel.

- The placement of the control stick in a center location aided slightly with the operation of the right hand console keyboard. I found I could hold the stick with my left hand and use my right to work the keyboard.

- The placement of the control stick in a center location interfered greatly with the operation of the right hand console keyboard because reaching for the buttons was awkward.

- The placement of the control stick in a center location aided greatly with the operation of the right hand console. I flew with my left hand and punched with the right. However, when doing this it's better to have the keyboard words to the left of the button so my hand doesn't cover the labels when punching.

II-3. The placement of the <u>control stick</u> in a <u>side</u> location

7/9 Interfered greatly with the operation of the right hand console keyboard

1/9 Interfered slightly with the operation of the right hand console keyboard

1/9 Did not interfere with the operation of the right hand console keyboard

Aided slightly with the operation of the right hand console keyboard

Aided greatly with the operation of the right hand console keyboard

Comments:

- Placement of the control stick in a side location interfered greatly with the operation of the right hand console keyboard because reaching for the buttons was awkward.

- Placement of the control stick in a side stick location made it hard to see the keyboard and maintain control of the aircraft.

- The placement of the control stick in a side location interfered greatly with the operation of the right hand console keyboard. Can't change hands.

II-4. The placement of the <u>control stick</u> in a <u>side</u> location

Interfered greatly with the operation of the front panel keyboard.

Interfered slightly with the operation of the front panel keyboard.

1/9 Did not interfere with the operation of the front panel keyboard

7/9 Aided slightly with the operation of the front panel keyboard

1/9 Aided greatly with the operation of the front panel keyboard

Comments:

- Nothing obstructed my view; thus, I could think about my operations as soon as the task was given and I determined the configuration.

- Side stick with front panels and right MPD instead of plasma panel on side should be very easy to operate. The pilot could easily monitor position, altitude, attitude, etc. while completing communication or navigation tasks.

- The placement of the control stick in a side location did not interfere with the operation of the front panel keyboard. The reason it did not aid me is because with a side stick I was more relaxed and leaned towards the stick more, thus making it harder to reach the front panel.

- Configuration with side stick gives you full unobstructed view of front panel.

II-5. The plasma panel was located either on the front panel or on the right hand console. Concerning the location of the plasma panel

9/9 Operation was much easier when the plasma panel was located on the front console

Operation was slightly easier when the plasma panel was located on the front console

Operational ease of the plasma panel was the same on the front console and right hand console

Operation was slightly easier when the plasma panel was located on the right hand console

Operation was much easier when the plasma panel was located on the right hand console

Comments:

- The plasma panel was almost unusable when on the right console and marginal on the center console for levels 1, 2, and 3. "A/N" input was impossible on right side.
- The switches not being aligned with the readout caused visual tracking (parallax) problems.
- You could tell at a glance what was happening.
- Even though the front console location was better, it doesn't mean I like that particular system.
- Easier on the front panel, however, keys are too close to use efficiently especially in turbulent flying conditions. Suggest staggering the buttons.
- There was still a problem aligning the plasma panel display with its relative button on the front panel, but not nearly as great as when it was on the right hand console.
- Parallax biggest problem. Also inefficient use of space anywhere.
- It was difficult to correspond buttons to functions when the plasma panel was on the side panel.
- Buttons on plasma panel were too small for operation with gloves on. Much parallax in lines connecting switches and numbers.

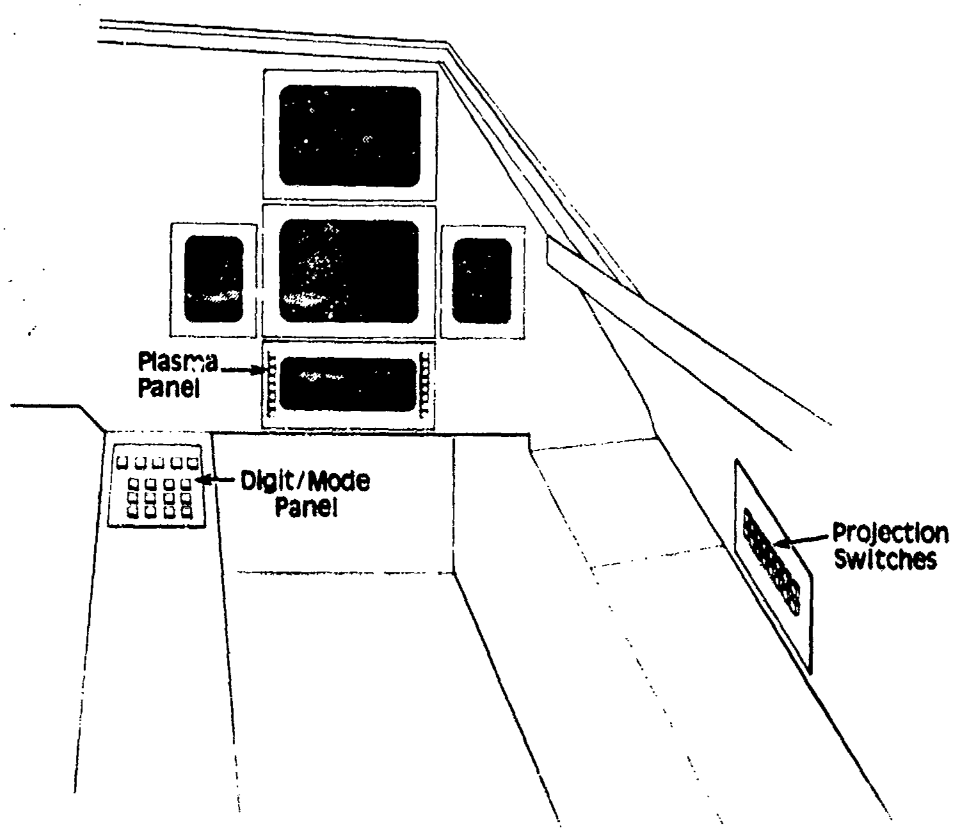


Figure D1. Locations of the multifunction keyboards.

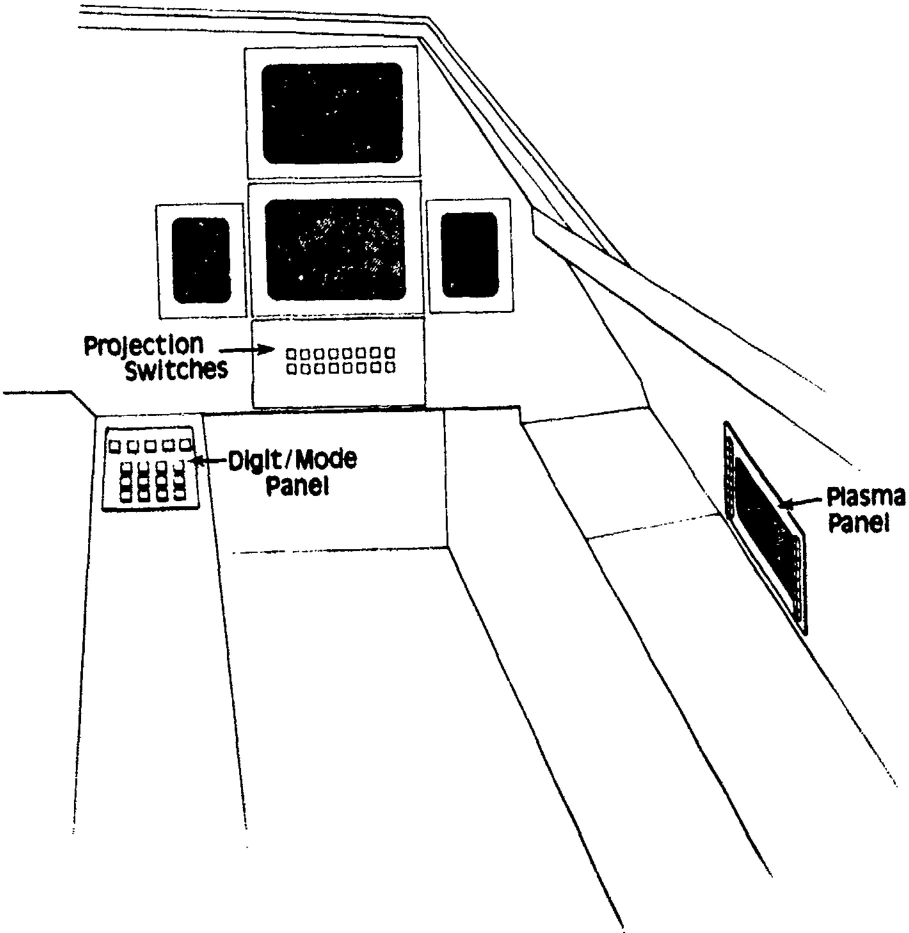


Figure D2. Locations of the multifunction keyboards.

II-6. The projection switches were also located either on the front panel or on the right hand console. Concerning the location of the projection switches

5/9 Operation was much easier when the projection switches were located on the front console

2/9 Operation was slightly easier when the projection switches were located on the front console

1/9 Operational ease of the projection switches were the same on the front console and right hand console

1/9 Operation was slightly easier when the projection switches were located on the right hand console

Operation was much easier when the projection switches were located on the right hand console

Comments:

- Ease of projection switches was a combination of head movement and visibility. Legibility of projection switches is not great and having them out front is a help.

- The lighted switch made the choice process much faster and as a backup would be easy to use.

- Operational ease of the projection switches were the same on the front console and right hand console. It was much easier than the plasma panel on the side as the buttons had the numbers/functions right on them.

- Operation of projection switches panel very easy. Buttons are large and well separated.

- Operation was much easier when the projection switches were located on the front console. But easier on side panel than plasma panel on side panel.

II-7. The legend on the plasma panel was

Very difficult to read

2/9 Moderately difficult to read

3/9 Moderately easy to read

4/9 Very easy to read

Comments:

- Except the parallax made it bad and the slanted lines necessary because the height of the button column is greater than the word panel. If the white guide lines from button to words were parallel and horizontal, it would be much better.
- Legend was moderately difficult to read, but difficult to track.
- Rather small letters and buttons to push.

II-8. Selecting the appropriate switch on the plasma panel from the available legend was

6/8* Very difficult

1/8 Moderately difficult

1/8 Moderately easy (*One subject did not indicate a response.)

Very easy

Comments:

- Parallax and lack of consistent association, i.e., top switch = top function, makes plasma panel the worst of the three and virtually unusable in the right hand console position.
- If the panel was set up properly (i.e., tailored logic concept mentioned by experimenter), I see no problem with operation.
- Very hard to figure out which button to push. Took a lot more concentration.

- Selecting the appropriate switch on the plasma panel from the available legend was very difficult. Only with plasma panel on right side panel. Moderately easy when on the front panel.

- Buttons are too close to use efficiently. Lines to readout from buttons are very deceptive if not looked at carefully and from head on.

II-9. How did the size of the switches and their proximity to each other on the plasma panel affect your ability to operate the keyboard while wearing flying gloves?

4/9 Made operation very difficult
4/9 Made operation moderately difficult
1/9 Did not affect operation
Made operation moderately easy
Made operation very easy

Comments:

- Size was a little small and they were too close together. But the left row was too far away from the right row to go back and forth.

- More space between keys would be helpful. Also, some changes in shape may be useful for night; i.e., raised dots or depressions for the first key of each column.

- Sizes of switches, etc. on plasma panel made operation very difficult. Only with plasma panel on right side panel. Moderately easy when on the front panel.

- Staggering buttons would facilitate ease of operation.

II-10. Considering your previous association of amber with emergencies, the amber color of the plasma panel legends was

Very confusing
Moderately confusing

9/9 Not confusing at all

Comments:

No comments.

LOGIC LEVEL 1		LOGIC LEVEL 2		LOGIC LEVEL 3		LOGIC LEVEL 4	
		UHF	CLEAR	UHF POWER	CLEAR		CLEAR
		VHF/FM		GUARD XMT		1/N	7
	COMM	ADF		SQLCH		2/S	8
	NAV	IFF		T/R		3/E	9
	SENSOR	RADAR BCN		ADF		4/W	0
	AIR-CRAFT					5	
						6	
					A/N		ENTER

Figure E1. Legends on plasma panel keyboard for each logic level step during a communication task.

LOGIC LEVEL 1		LOGIC LEVEL 2		LOGIC LEVEL 3		LOGIC LEVEL 4	
		NAV COMP	CLEAR	COMP POWER	CLEAR		CLEAR
		LORAN		DPLR		1/N	7
	COMM	TACAN		WAY PNT		2/S	8
	NAV	NAV UPDATE		FLY TO		3/E	9
	SENSOR	ILS		MARK		4/W	0
	AIR-CRAFT	MOVING MAP				5	
						6	
							ENTER

Figure E2. Legends on plasma panel keyboard for each logic level step during a navigation task.

II-11. How did the placement of the digit "1/N" on the plasma panel (second key on left) affect your operation of the keyboard?

3/9 Made operation very difficult

4/9 Made operation moderately difficult

1/9 Did not affect operation

1/9 Made operation moderately easy

Made operation very easy

Comments:

- Should have been placed to be operated by top switch. Tape lines were of little help since they ended between words on the panel and were very confusing.

- I tended to associate the "1/N" digit with the first key on top.

- The placement of the digit "1/N" on the plasma panel made operation very difficult. Only with plasma panel on right side panel.

II-12. Can you improve on the plasma panel arrangement of the digits and the north, south, east, and west symbols?

	CLEAR		
1/N	7		
2/S	8		
3/E	9		
4/W	0		
5			
6			
	ENTER		

Responses:

1/N	9
2/S	0
3/E	CLEAR
4/W	ENTER
5	
6	
7	
8	

X	X
1/N	CLEAR
2/S	7
3/E	8
4/W	9
5	0
6	ENTER
X	X

X - Eliminate

1/N	6
2/S	7
3/E	8
4/W	9
5	0
CLEAR	ENTER

1/N	6
2/S	7
3/E	8
4/W	9
5	0
	CLEAR LAST ENTRY
ENTER	CLEAR

1/N	6/E
2	7
3	8
4	9
5/S	0/W
	ENTER

1/N	6
2/S	7
3/E	8
4/W	9
5	0
CLEAR ENTER	

1/N	6
2/S	7
3/E	8
4/W	9
5	0
ENTER	CLEAR

ENTER	CLR
1/N	6
2/S	7
3/E	8
4/W	9
5	0

1/N	6/E
2/S	7/W
3	8
4	9
5	0
ENTER	CLEAR

Comments:

- Would have to try several combinations. Perhaps enter button should be in lower left column.

- Is it possible to take the 8 spaces and make them into 6, thereby making each digit larger? The enter key was very hard to reach no matter where the location of the keyboard was.

- This type of key placement would cut down greatly on entry errors. You could also enter numbers by "touch" since all odd numbers are in the outside rows and even numbers on the inside rows.

```
1/N          P
       2     A   6/E
 3           N          7
       4     E    8
5/S          L          9
                 0/W   ENTER
```

- Any layout isn't going to be really good unless the panel is angled to deal with parallax.

II-13. The legend on the projection switches was

Very difficult to read

1/9 Moderately difficult to read

3/9 Moderately easy to read

5/9 Very easy to read

Comments:

- Though easier than any other to read and punch, perhaps the numbers themselves could be larger.

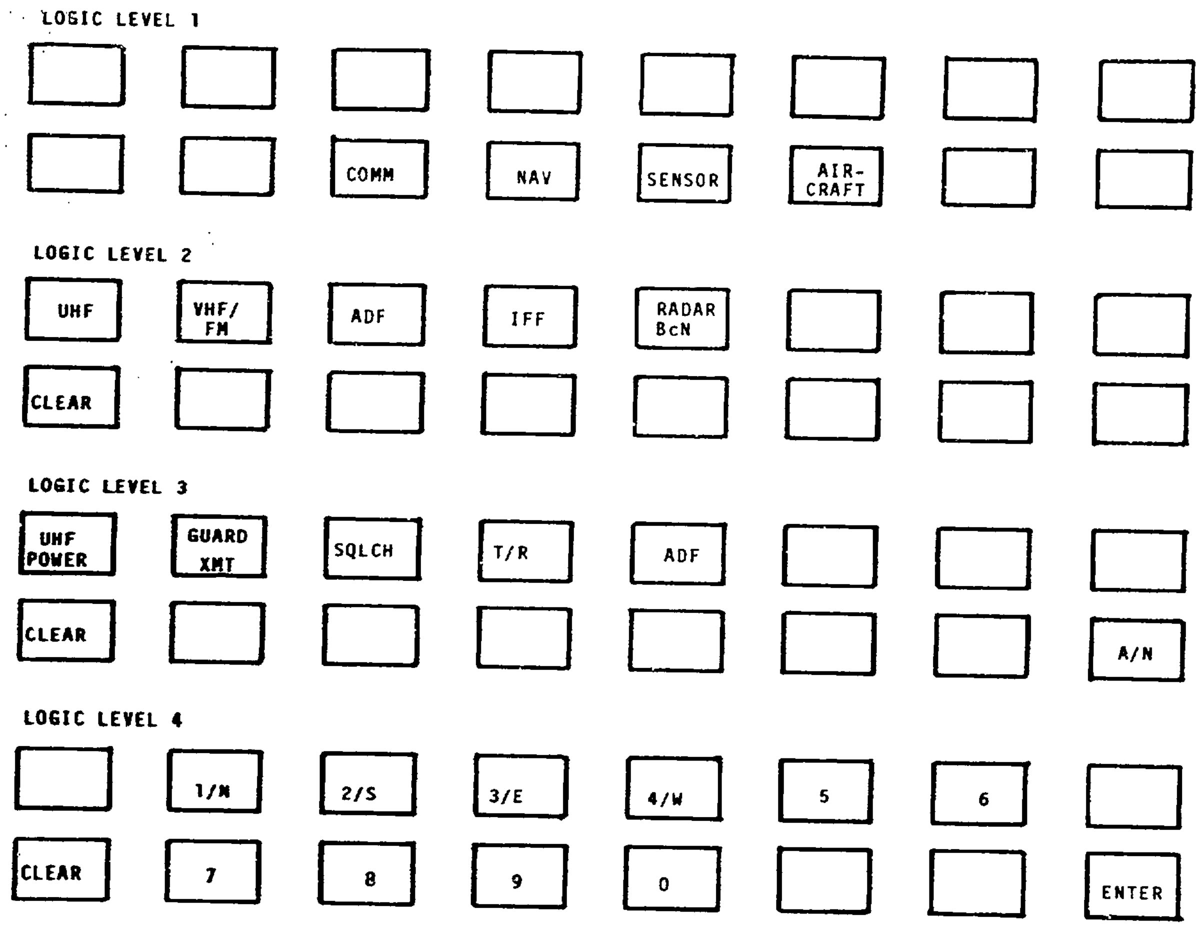


Figure F1. Keyboard legends on projection switches for each logic level step during a communication task.

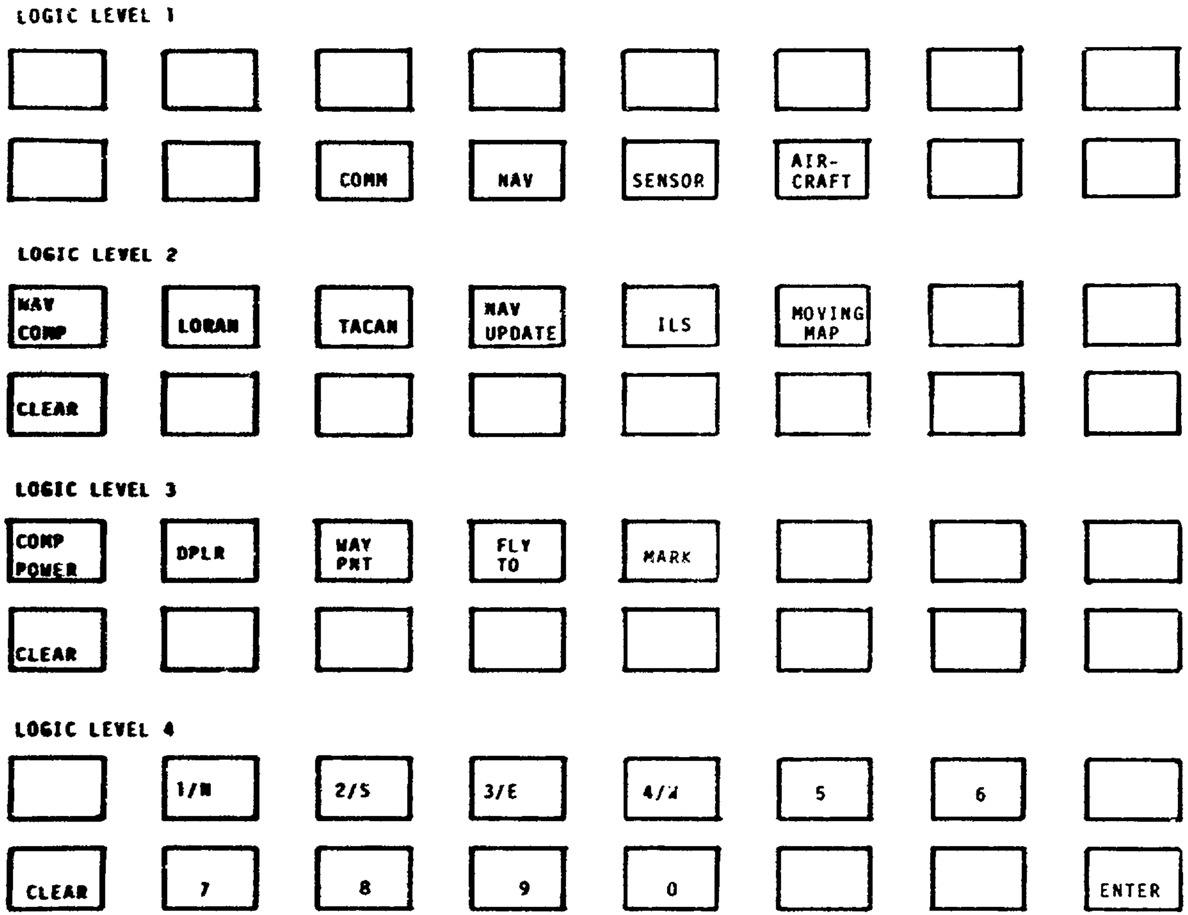


Figure F2. Keyboard legends on projection switches for each logic level step during a navigation task.

II-14. How did the size of the switches and their proximity to each other on the <u>projection switches</u> affect your ability to operate the keyboard while wearing flying gloves?

1/9 Made operation very difficult

Made operation moderately difficult

3/9 Did not affect operation

2/9 Made operation moderately easy

3/9 Made operation very easy

Comments:

- Characteristics of the projection switches made operation moderately easy. No problems with it, except on the side panel. Then this configuration is too long for easy manipulation.

II-15. How did the placement of the digit "1/N" on the <u>projection switches</u> (second key from left) affect your operation of the keyboard?

Made operation very difficult

1/9 Made operation moderately difficult

8/9 Did not affect operation

Made operation moderately easy

Made operation very easy

Comments:

- Placement of "1/N" button on projection switches made operation moderately difficult. Should be first digit.

- As with the plasma panel, you can eliminate the extra switches.

- Placement of "1/N" digit made operation moderately difficult. This difficulty would probably be overcome with more use of one keyboard; e.g., as you would have in an aircraft that you are qualified in.

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- The placement of "1/N" on the projection switches did not affect operation. Except I didn't like the first blank key.

II-16. Can you improve on the projection switches arrangement of the digits and the north, south, east, and west symbols?

	1/N	2/S	3/E	4/W	5	6	
CLEAR	7	8	9	0			ENTER

Responses:

1/N	2/S	3/E	4/W	5	6		
ENTER	7	8	9	0	CLEAR		

	1/N	2/S	3/E	4/W	5		
CLEAR	6	7	8	9	0		ENTER

1/N	2/S	3/E	4/W	5			ENTER
6	7	8	9	0		CLEAR LAST ENTRY	CLEAR

X	1/N	2/S	3/E	4/W	5	6	X
X	CLEAR	7	8	9	0	ENTER	X

X - Eliminate

1/N	2/S	3/E	4/W	5	6	7	8
9	0	ENTER					CLEAR

SYSTEM IS VERY GOOD IN PRESENT CONFIGURATION

	1/N	2/S	3/E	4/W	5		
CL	6	7	8	9	0		ENTER

				NO			

1/N	2/E	3	4	5			ENTER
6/S	7/W	8	9	0			CLEAR

Comments:

- "ENTER" on the far right makes it too far aft when panel is mounted on right side.

II-17A. Concerning the ease of operation of the plasma panel and projection switches when both were located on the front panel

Plasma panel was much easier than the projection switches

Plasma panel slightly easier than the projection switches

1/9 Plasma panel was equally easy as the projection switches

2/9 Projection switches were slightly easier than the plasma panel

6/9 Projection switches were much easier than the plasma panel

Comments:

- Projection switches were much easier than the plasma panel. Due simply to button size and arrangement.
- Projection switches were slightly easier than the plasma panel, due to aligning stripes on plasma panel.
- Projection switches were much easier than the plasma panel. You read what you touch (what you see is what you get) on the projection switches.
- No question about it. Projection switches were much easier on the front panel than the plasma panel.

II-17B. Concerning the ease of operation of the plasma panel and projection switches when both were located on the right hand console

Plasma panel was much easier than the projection switches

1/9 Plasma panel was slightly easier than the projection switches

1/9 Plasma panel was equally easy as the projection switches

Projection switches were slightly easier than the plasma panel

7/9 Projection switches were much easier than the plasma panel

Comments:

- There was a great deal of parallax in the plasma panel which added greatly to an already difficult situation.
- Plasma panel very difficult to operate. Pilot's line of sight caused many erroneous entry errors (one digit off). Lines from readout to buttons deceptive. If used in this location, panel should be tilted out to a better reading angle.
- Both gave me problems, but it seemed as though I could tell at a glance. Plasma panel was slightly easier than the projection switches on the right hand console.
- Projection switches were much easier than the plasma panel. Not due to overwhelming superiority of projection switches, but due to overwhelming deficiencies of plasma panel when mounted on right side.
- Projection switches were much easier than the plasma panel when located on the right hand console. Due to aligning stripes on plasma panel. Plasma panel could possibly be arranged to let the pilot look more directly onto panel.

II-18. Activation of the fourth logic level differs between communication and navigation tasks on both the plasma panel and projection switches. In order to activate the digits in a communication task, the operator must select the bottom right switch labeled "A/N". For the navigation task, the operator must select the third from the left switch labeled "waypoint". How did the difference in the positioning of the switch that activates the digits affect your operation of these keyboards?

	Made operation very difficult
3/9	Made operation moderately difficult
6/9	Did not affect operation
	Made operation moderately easy
	Made operation very easy

Comments:

- The difference between keyboards in the positioning of the switch that activates the digits made operation moderately difficult. At first it was difficult to go over to A/N, but after a while I could do it rather unconsciously.
- The difference between keyboards in the positioning of the switch that activates the digits made operation moderately difficult. You should have to remember only one switch position so that you can go back to habit patterns and not have to think about operation when things are going wrong, or when you have to fly a difficult approach in weather.
- A/N should not be required as the computer can be programmed to know that digits will be entered.

- Would be easier if the most common use in Nav; i.e., "waypoint" were in the same place as "A/N" either in the third slot or the last.

- Placements of "A/N" and "waypoint" did not affect operation. However, "A/N" would be easier to use if positioned on same side of keyboard.

II-19. In regards to the fourth logic step, how did the placement of the "enter" button in the bottom right position on both the projection switches and plasma panel affect your operation of the keyboards?

Made operation very difficult

1/9 Made operation moderately difficult

5/9 Did not affect operation

2/9 Made operation moderately easy

1/9 Made operation very easy

Comments:

- Position of "enter" did not affect operation. I would have liked it better in bottom left since I do all operations left handed. I don't remove my right hand from stick.

- "ENTER" on the far right makes it too far aft when panel is mounted on right side. Also, causes left hand work on right side of cockpit when mounted on front. Possible interference with center stick.

II-20. How did the placement of the digits in a 789 manner on the digit mode panel affect your operation of the keyboard?

```
789
456
123
COE
```

1/9 Made operation very difficult

1/9 Made operation moderately difficult

3/9 Did not affect operation

1/9 Made operation moderately easy

3/9 Made operation very easy

Comments:

- Very good arrangement. Since zero is the most often used number, it should be the closest and most convenient.
- I had not used such a configuration before and thus it was hard at first. During the time I was flying the simulator, I purchased a calculator with a similar keyboard and had no problem from that point on. I can see no great problems with it.
- Placement made operation moderately easy. I'm used to using an adding machine left handed with the same digit layout.
- I think pilots could get used to any pattern.

II-21. Figure G shows several digit arrangements. The first arrangement was the one you used for the digit mode keyboard in the experiment. The second and third are like the arrangements on most telephones and calculators, respectively. We need to know whether any improvements need to be made on the arrangement of the digits and the North, South, East, and West symbols. Indicate on Figure G which arrangement you like best or else write in your suggestion on the blank arrangement provided.

Comments:

-

CLEAR	0	ENTER
7	8	9
4/W	5	6
1/N	2/S	3/E

1/N	2/S	3/E
4/W	5	6
7	8	9
CLEAR	0	ENTER

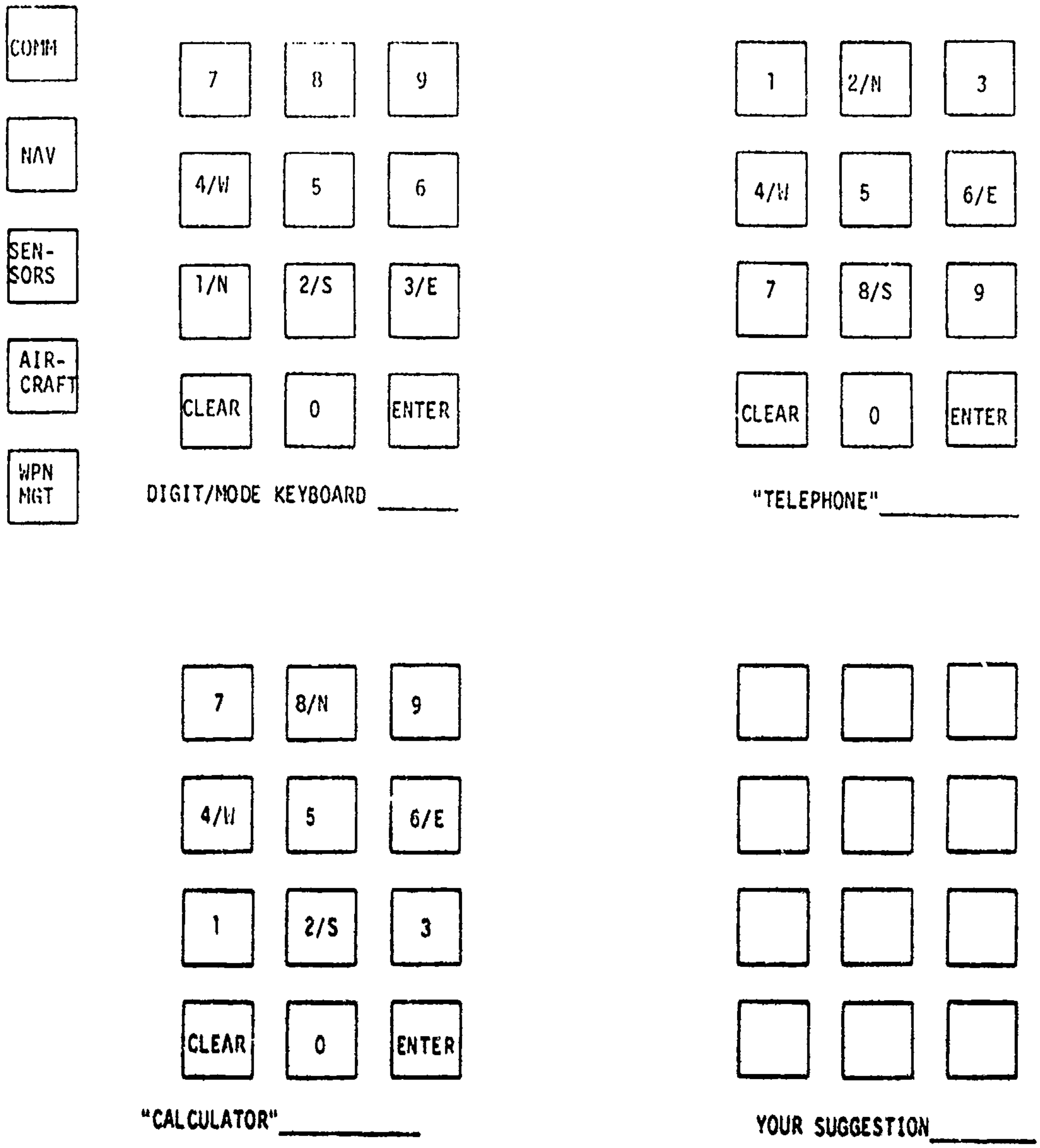

Figure G. Keyboard Digit Arrangements.

- I believe that any of the arrangements would prove to be feasible. However, a distinctive key such as a bump or a different light could be put on the 5 for a starting point so that a person doesn't have to look down as much.

- Calculator arrangement most desirable.

- Calculator.

- Calculator.

- Digit/mode keyboard. I like this keyboard because "1/N" etc. would always be the same on all keyboards.

- Telephone.

- "Calculator" arrangement gives a more logical arrangement of compass points.

II-22. Figures E, F, and G depict the logic steps available on each type of keyboard. Do you have any additional comments in regards to the legends used or their position on the keyboards?

- The legends are fine, but extra keys could be eliminated and displays slightly more condensed.

- Plasma panel - logic level 1 should be on the left hand of the panel. That would put the first 4 or 5 entires on the left. If both of these panels were used in the same aircraft, why not arrange the labels in a similar pattern since each one has only two rows or two columns. On any panel, some increased accuracy may be available if you put a plasma print out of the entry prior to "enter" across the top edge of that panel.

- Plasma panel - Prefer to have logic level 1 on column 1 starting with first button. Dislike placement of "A/N". The most important drawback to plasma panel is the parallax problems involved in associating the button with proper display.

- Plasma panel - logic level 1 - place legends on upper left 4 keys. Plasma panel - logic level 4 - do not skip keys. Same thing for projection switches.

SECTION III

DISPLAY QUALITY AND APPROPRIATENESS OF FORMATS USED

The formats of the information presented on the displays embodied one assessment of the information requirements for this type of mission. We are interested in your reactions to these formats. Interest in the display format question is two-fold: (1) whether or not the information displayed is adequate; and (2) whether or not the format is easily understood and interpreted. In addition, questions are included for you to evaluate the quality of the displays and handling characteristics of the simulator. For each of the following questions, fill in the circle which most nearly conforms to your opinion. Figures H - L depict some of the formats presented on the electro-optical displays.

III-1. On the EADI, the following information was presented: pitch, bank, airspeed, altitude, heading, flight director, acceleration, vertical velocity, and aircraft symbol. For utilization during flight, this information package was

1/9 Excessive

6/9 Sufficient

2/9 Insufficient

Comments:

- Trend information on heading and altitude were either missing or hard to pick up.
- Information was adequate, method of presentation bad.
- Heading gives insufficient information. A complete directional gyro indicator should be installed separately.
- EADI information sufficient. Everything other than acceleration is required for good instrument crosscheck. However, having it on EADI is as good as any place and saves space.

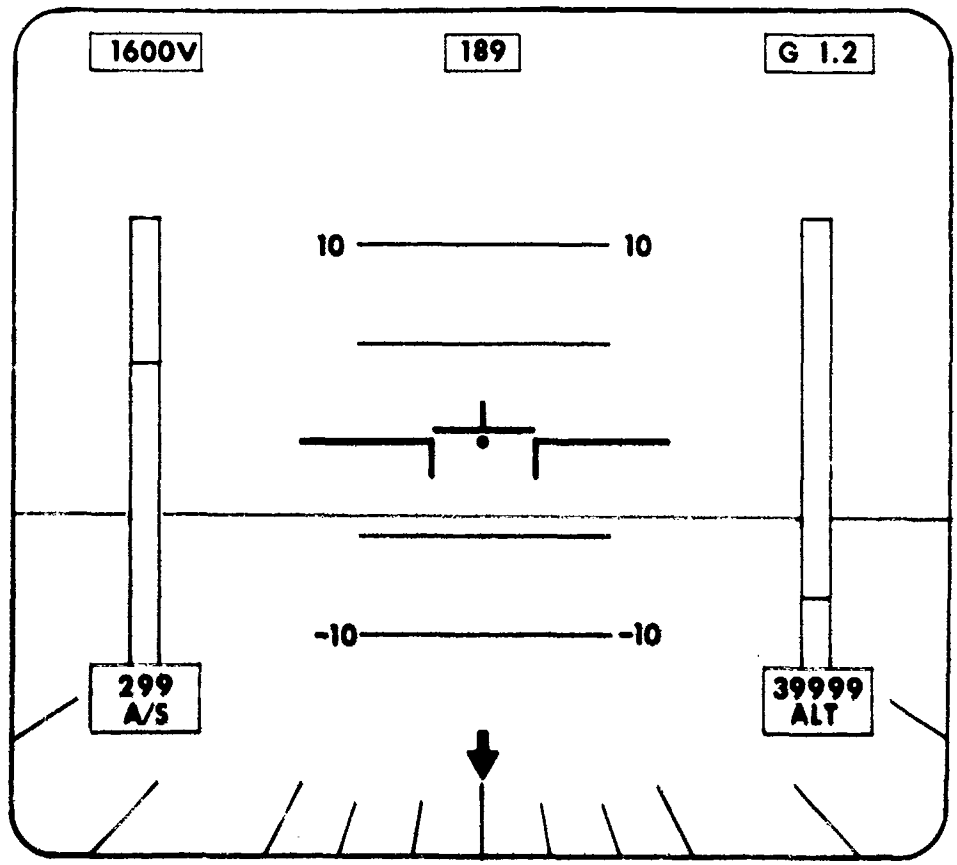

Figure H. EADI display format.

- "G" was fun to watch, but not very important for this simulation. Need angle of attack.

- Excessive. "G" not used. Altitude to 5 digits is excessive and distracting when at altitude. Generally, 3 significant digits is all I worry about.

III-2. If you found the information displayed on the EADI excessive, which of the following would you eliminate

Pitch		2/9	Heading
Bank			Flight Director
Airspeed		3/9	Acceleration
Altitude		1/9	Vertical Velocity
			Aircraft Symbol

- Heading and acceleration excessive. Depends on rest of displays available in cockpit.

- I would like to see the "G" meter and VVI exchanged.

- Eliminate heading on EADI if it is on lower CRT or if flight director is operative. The carrot (sic) symbol of the vertical velocity is too hard to use with peripheral vision. Maybe another tape presentation would be better next to the altitude strip.

III-3. If your found the information displayed on the <u>EADI</u> insufficient, what would you add?

- It might be necessary to display the altimeter setting somewhere. On most aircraft, mach number is not only useful, but is often a limiting factor. On most ADIs, the bank pointer is called the sky pointer and is located at the top of the ADI. This might cause some confusion.

- When the desired pitch is on or near a pitch index line, and you are centering the flight director symbol, precise pitch control is not possible since the symbols cover the pitch index.

- More trend information on heading. Perphaps 5 numbers instead of 1. The VVI pointer carrot (sic)was very difficult to read and should be bigger.

- Angle of attack.

- Need trend information for vertical velocity, heading, airspeed, altitude. Find it difficult and time consuming reading digital information for airspeed and altitude.

III-4. Rate the following information presented on the EADI in regards to the ease of retrieval

Locating the information was:

	Very Easy	Moderately Easy	Moderately Difficult	Very Difficult
Pitch	8/9	1/9		
Bank	7/9	1/9	1/9	
Airspeed	6/9	2/9	1/9	
Altitude	5/9	3/9	1/9	
Heading	2/9	5/9	2/9	
Flight Director	6/9	3/9		
Acceleration	3/9	5/9	1/9	
Vertical Velocity	2/9	2/9	4/9	1/9
Aircraft Symbol	8/9	1/9		

- Bank - too far away from pitch index. VVI - I rarely used it. Airspeed and altitude - easy only if desired number is at one end of the scale.

- Need finer pitch scaling.

- EADI information location excellent.

- Because of the type of flying that we were doing, the heading function did not come into my crosscheck.

- I used the altitude and airspeed vertical bars almost entirely for the testing. Gives you all your information in one quick glance. In turbulence during flight, I think you would have difficulty in reading the small digits.

III-5. Rate the following information presented on the EADI according to the degree to which the information was easy to understand

Understanding the information was:

	Very Easy	Moderately Easy	Moderately Difficult	Very Difficult
Pitch	7/9	1/9	1/9	
Bank	6/9	2/9	1/9	
Airspeed	6/9	1/9	2/9	
Altitude	3/9	3/9	3/9	
Heading	3/9	4/9	1/9	1/9
Flight Director	7/9	2/9		
Acceleration	5/9	3/9	1/9	
Vertical Velocity	2/9	4/9	3/9	
Aircraft Symbol	7/9	1/9	1/9	

Comments:

- With a digital VVI that is instantaneous, the display changes so rapidly at times that reading it accurately became very difficult. I would also say that the increasing/decreasing sign is inadequate. The airspeed indicator needs to be calibrated. The altitude trend indicator would be better utilized if it weren't constantly switching from full to zero deflection. Since most of the flying is done at altitudes such as 31,000, 24,000, and 8,000, I would suggest centering the thousand or zero marks and scale it plus or minus 500.

- Airspeed and altitude - moderately difficult. With thermometer displays of this type, the pilot pays a penalty for being accurate. Unfortunately, I seldom had the problem but those who fly accurately would be rattled by the tape changing constantly from full to empty, to full...! Refresh rate seemed extremely slow in dynamic maneuvering. Would have to see both axes to evaluate. What would happen if steering was bad in one axis?

- Altitude - too many significant digits. Acceleration and VVI - rarely looked at or cared. Understanding EADI information excellent.

- An adjustable pitch trim knob is needed. The blue-brown horizon is excellent - the degree of bank would be better shown as a sky pointer than a ground pointer. The moving vertical line for airspeed and altitude is terrible. Indications of going "over the top" is very confusing. Interpreting rate from a vertical moving line is very difficult and the digital readout is too small and difficult to read. Heading digital readout is good, but too small. Acceleration is out of field of view and no indication of rate. Almost unusable. Vertical velocity digits too small and rate indicator completely inadequate. During rapid rate change, you can go from climb 3000 to descent 3000 without showing the rate of change passing zero. Very unrealistic.

- Vertical velocity needs to be interpretable at a glance, not necessarily by reading it. The carrot (sic) symbol was too small. Attitude bar wasn't the best way to do it eitner. Seeing a lot of bar didn't necessarily mean that you were way off altitude. I think a bar with the desired altitude in the middle with a visible reference line would be better. Above the reference you're high; below, you're low. Same for airspeed. Heading could have been bigger and required too much mental arithmetic to figure intercepts and such. Didn't give good idea of rate of turn to figure lead points for rolling out on a desired heading. Having a compass rose as in a normal HSI is very handy for basic instrument work. Excellent flight director. Needs angle of attack display.

- Heading needs to show a trend to help establish roll in/out points. VVI could have larger carrot (sic) symbol.

- At a glance it was hard to tell exactly how much bank you were in. The heading indicator should have trend information on it. The VVI pointer carrot (sic) should be a lot bigger.

III-6. On the <u>HSD</u>, the following information was presented: track, waypoints, aircraft location, heading, ground speed, and distance to the next waypoint. For utilization during flight, this information package was:

	Excessive
8/9	Sufficient
1/9	Insufficient

Comments: None

III-7. If you found the information displayed on the <u>HSD</u> excessive, which of the following would you eliminate:

	Track
	Waypoints
	Aircraft Location
1/9	Heading
	Ground Speed
	Distance to Waypoint

Comments:

- Distance to waypoint is sufficient to NM only. Going to feet when close to waypoint not needed. Your position changes too rapidly when flying 6 to 8 miles a minute. Feet information not needed.

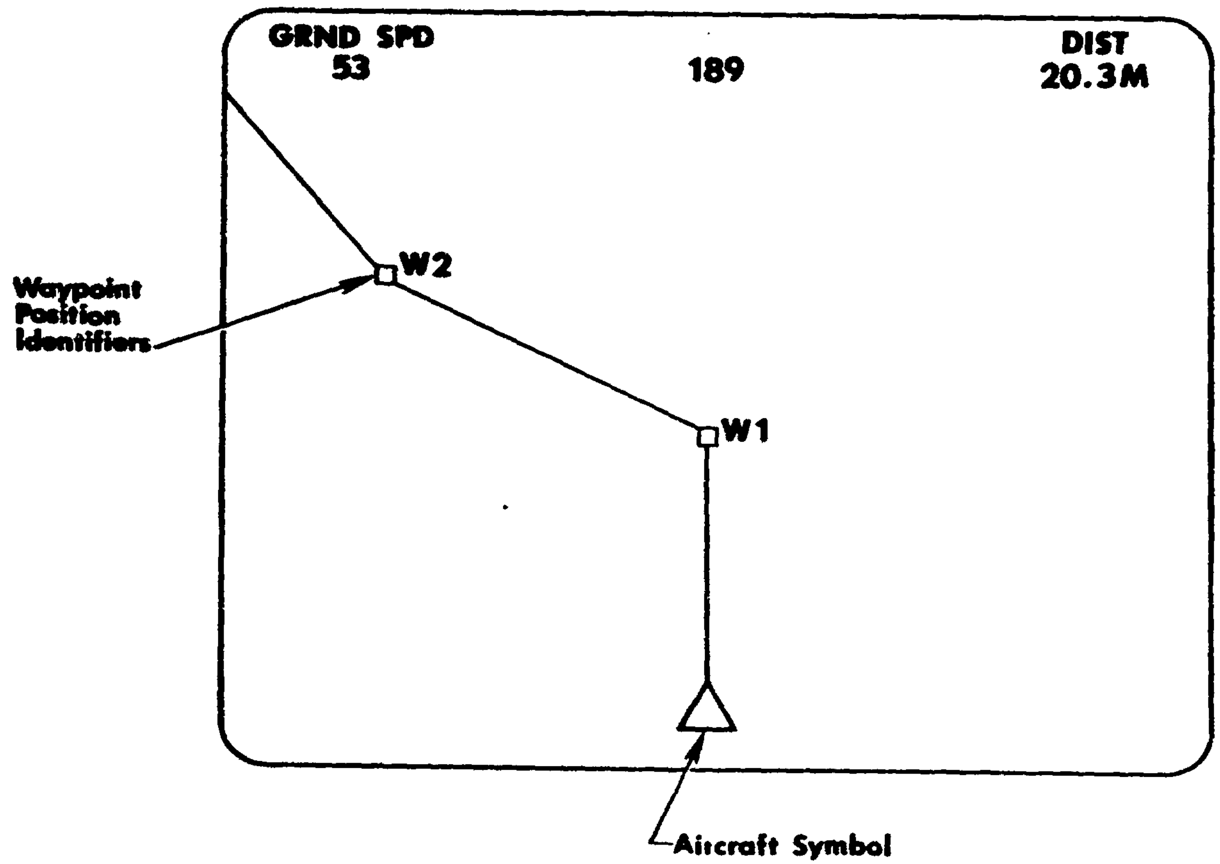

Figure I. HSD map display format.

- Heading - no need for a redundant readout, especially with the flight director working.

III-8. If you found the information displayed on the HSD insufficient, what would you add?

- Had some problem remaining oriented to the real world. An improved heading display on the EADI or HSD may help and a feature should be added to allow the pilot to switch to north up display.

- Digits were sometimes too small on the green light scope. One time I mistook a 1 for a 2. I wanted magnetic course and length of each leg printed next to the leg I was on.

- Somewhere in the cockpit a compass rose is needed.

- Time to waypoint might be another consideration.

III-9. Rate the following information presented on the HSD in regards to the ease of retrieval.

Locating the information was:

	Very Easy	Moderately Easy	Moderately Difficult	Very Difficult
Track	9/9			
Waypoints	9/9			
Aircraft Location	7/9	1/9	1/9	
Heading	5/9	4/9		
Ground Speed	7/9	2/9		
Distance to Waypoint	7/9	2/9		

Comments:

- Move ground speed and distance to waypoint toward center. Why use corners. It expands necessary crosscheck area. Digits should also be larger.

- In regards to your normal heading indicator, much more convenient to have a complete compass card.

III-10. Rate the following information presented on the HSD according to the degree to which the information was easy to understand.

Understanding the information was:

	Very Easy	Moderately Easy	Moderately Difficult	Very Difficult
Track	9/9			
Waypoints	9/9			
Aircraft Location	7/9	1/9	1/9	
Heading	4/9	3/9	1/9	1/9
Ground Speed	7/9	2/9		
Distance to Waypt.	7/9	2/9		

Comments:

- There must be a better symbol for an aircraft than an isoscles triangle. That made it difficult to interpret heading even when you knew you were on course. How about when you find yourself in an unusual altitude and lost.

- I would usually prefer to use a proportion of the known leg length to determine distance to next waypoint, unless precise number was needed.

- Heading and aircraft location moderately difficult in relation to a compass because you're just looking at one heading number.

- Heading - very difficult to understand information. I knew where to find, but I couldn't use it.

- Ground speed and distance indicators could have been closer to the display.

III-11. In reference to the legs of the mission track presented on the HSD, the display changed to a jagged line when the aircraft was off the specific heading. How did this presentation affect the tracking task?

1/9 Made the tracking task much easier
2/9 Made the tracking task somewhat easier
5/9 Did not affect the tracking task
1/9 Made the tracking task somewhat difficult
Made the tracking task much more difficult

Comments:

- A nice convenience, but not necessary. Flying involves a continual change of headings and power settings to maintain desired track and altitude.

- This feature made the tracking task somewhat easier. It was the only way I could get a feel for how my heading varied from the course line, since you didn't tell me what the course really was. Even with the known course, this is not easy due to relative heading (without some type of vertical grid system).

- This feature did not affect the tracking task. Sorry, but I seldom tried to obtain perfection due to control response and sensitivity, and associated tendency to over control. Accordingly, a "close enough for government work" attitude set in, particularly during switching tasks. If the bank command was close to center and aircraft was on track, I didn't care whether the line was smooth or jagged.

Rate the following display qualities according to the scales provided and make a mark in the appropriate box. When making additional comments, include the number referring to the specific display quality.

III-12. EADI (Fig H)

Display Qualities

	Very Unacceptable	Unacceptable	No Opinion	Acceptable	Very Acceptable
1. Legibility		2/9		4/9	3/9
2. Brightness				4/9	5/9
3. Color				4/9	5/9
4. Shape of Symbols		1/9		4/9	4/9
5. Jitter	1/9	2/9		4/9	2/9

Comments:

- I like having the VVI below the altimeter and in instrument approaches it is important. On the airspeed and altitude displays, I would prefer removal of the letters and making the numbers larger, especially the altimeter. The trend bars on either side are quite useful, but I don't really think they need to be quite so large. The aircraft symbol center dot needs to be more distinct because when its superimposed on the flight director, you lose positive control of aircraft and have to resort to altimeter and VVI since you cannot see exactly what pitch the airplane is at.

- Legibility - in rough air flying, it would be difficult to read the small number displays. Therefore, the vertical bars are a great aid.

- Jitter - it sometimes gave me a distortion of view, as though the lines were floating.

- Legibility - unacceptable. Find it difficult and time consuming reading digital information for airspeed and altitude.

Shapes of symbols - unacceptable. Basic aircraft symbols are probably ok, perhaps they should be finer. Other displays don't like. Jitter - very unacceptable. When attitude was changing.

- Jitter somewhat distracting at first. (acceptable)

- Can color change when there are large deviations in VVI, airspeed, and "Gs"? Also, intensity change at night?

- Brightness and color very acceptable. Great now. How about after CRT gets old? Will they fade?

III-13. HSD (Fig I)

Display Qualities

	Very Unacceptable	Unacceptable	No Opinion	Acceptable	Very Acceptable
1. Legibility		1/9		5/9	3/9
2. Brightness				5/9	4/9
3. Color				5/9	4/9
4. Shape of Symbols				5/9	4/9
5. Jitter	1/9			6/9	2/9

Comments:

- Legibility of digits unacceptable.

- Jitter - very unacceptable. Sometimes parts of the display would disappear for a noticeable period of time.

- You are not concentrating on the HSD as intently as the EADI, so the jitter is not noticeable.

- A compass rose is needed for reference. It would also help if the pilot could annotate how the waypoints correlate to outside reality.

III-14. Certain information pertaining to communication and navigation was presented on the MPD. In your opinion, for each of the two formats, was this information:

Comm	Nav	
2/8 *	2/8	Excessive for utilization during flight
6/8	6/8	Sufficient for utilization during flight
		Insufficient for utilization during flight

* One subject did not indicate a response.

Comments:

- Too many systems listed in both "comm" and "nav" displays. Too cluttered. You need only to know whether a system is "on" or "off." Therefore, display only what is "on" because you know what you're using. In the same regard, if it doesn't appear on the MPD, you'll know it's "off."

- Because of the type of mission we're flying, tended not to use this information.

- Never really paid much attention to NAV status.

- I really didn't spend enough time looking at the information on the MPD to evaluate it.

NAV STATUS

BEARING	DIST	
346	800F	
FROM	TO	T. HEADING
P.P.	3	359

TIME TO SELECTED WAYPOINT

0 HRS 0′ 20″

GND SPD	DRIFT ANGLE
53 KTS	000R

NAV. MODE	TCN	SAT	SCALE
D.I.S.	126	26	40M

PRESENT POSITION	WAYPOINT
N 15 42′ 06″	
E 108 15′ 03″	

Figure J. Multipurpose display format for navigation status.

COMM STATUS

SUBSYSTEM	PWR	CHAN	FREQ
CMD UHF	OFF	1	335.05
VHF/FM	OFF	2	XXX.XX
ADF/AUX UHF	ON	3	XXX.XX

		MODE	PWR	CODE
IFF	OFF	1	ON	005
		2	ON	201
		3/A	OFF	0000
		C	ON	156
		4	OFF	304
RADAR BCN	ON			929

Figure K. Multipurpose display format for communication status.

III-15. Interpretation of the information on the MPD pertaining to communication and navigation was:

Comm	Nav	
1/8 *	1/8	Very easy
6/8	6/8	Moderately easy
1/8	1/8	Moderately difficult
		Very difficult

*One subject did not indicate a response.

Comments:

- I had to continually search for things because tasks did not involve much use of this information.

- Some NAV data could be put on HSD. I think the digits are too small compared to the size of other symbols in the cockpit.

- Too cluttered. Until you were used to the position of the various readouts, you'd have to go through the entire list of displayed material to find what you wanted to know.

- Left MPD was too cluttered and printing was too small. You had to search for information - distracting from primary task.

- MPD pre-entry readouts should be larger for easier use during cross checks.

III-16. Interpretation of the information on the MPD pertaining to failure warnings was:

5/7*	Very easy
1/7	Moderately easy
1/7	Moderately difficult
	Very difficult
	*Two subjects did not indicate a response.

Comments:

- I think the digits are too small compared to the size of other symbols in the cockpit.

- Lettering should be larger.

- Never used because it was unnecessary, since you only had to be aware of the lighted panels in the problems presented.

- A nice convenience, but you need only to know what panel you should be working on.

- Master caution light was good. Printing, again was too small and hard to read.

- Perhaps in addition to failure warnings, you could have a checklist page to refer to on the display.

- Possibly unnecessary as the proper panel to use was illuminated for each large logic level step.

FP KEYBOARD FAIL
USE RC FOR 2, 3

Figure L. Multipurpose display format for keyboard failure warnings.

Even though the simulator flying qualities were designed to keep you busy, we are still interested in rating the simulator. Rate the following simulator qualities according to the scales provided and make a mark in the appropriate box. When making additional comments, include the number referring to the specific simulator quality.

III-17. Simulator Qualities

The performance of the simulator can be broken down into the following qualities:

(1) The degree to which the electronically generated symbology on the displays moves dynamically in real time in RESPONSE to the action of the control stick. This response quality refers specifically to the displayed pitch, bank, flight director, track, and waypoints.

(2) The degree to which the dynamic response of the displays to the control stick action was SMOOTH in contrast to abrupt.

(3) The degree to which the symbology on the displays follows the appropriate DIRECTION as determined by the control stick action.

(4) The degree to which displayed flight parameters (airspeed, altitude, heading, acceleration, bearing, and ground speed) are REALISTIC INDICATIONS of the aircraft's state in the particular portion of the mission.

	Very Unacceptable	Unacceptable	No Opinion	Acceptable	Very Acceptable
1. Response		2/9		2/9	5/9
2. Smoothness		1/9		6/9	2/9
3. Direction				5/9	4/9
4. Indicators	1/9	1/9		4/9	3/9

Comments:

- Response unacceptable. Much too sensitive. Smoothness acceptable. Difficult to be absolutely sure without motion. Indicators unacceptable. The airspeed was tied too closely with throttle and not enough with pitch. The vertical velocity was tied too closely with pitch and not enough with throttle.

- Indicators acceptable. Tapes might be more useful if desired level were set as an index in the middle of the tape.

- Stick has slightly too much centering force. Feels too spring loaded. Side stick is canted too far back requiring operation by middle two fingers and thumb, which is usually on trim or mike buttons. Inadvertent operation of these buttons is too easy and stick is not very comfortable.

- The vertical velocity was unrealistic. It very rarely indicated "0". During flight with smooth control inputs, it could vary from 500 climb to 500 descent continuously.

- Very responsive!

- Smoothness acceptable. Sometime you had to be a little jerky on the control stick to get the display to move, instead of applying gentle, smooth control pressure on the stick, especially with the side stick. This occurred primarily when it was well trimmed. Also, the airspeed did not fall off as rapidly as it would in real life after rolling into 60-90 degrees bank with no power increase.

- Indicators unacceptable. No real trends as to heading and changes in airspeed or altitude.

Use this page for any additional comments you might have concerning this multifunction keyboard evaluation.

- I personally always fly your type cockpit with may right hand and do tasks with my left. On your numeric displays, a single digit clear function would be the best thing you could install.

- Possibly if the entire system could be incorporated into a simulator with motion, a better evaluation could be given. Overall, I thought the system was excellent and probably the only exception would be the plasma panel and I would recommend that if at all possible it be eliminated and replaced, or improved upon as previously suggested.

- I left off the heading display. The pilot should have a separate directional gyro. Heading is simply not enough.

  The best indicators on the EADI as far as "fast scan" instruments are the altitude and speed bars. Two excellent indicators! They give your trend indications plus readout. By "trend" I mean speed at which you are departing or getting to your assigned altitude or airspeed.

- On the EADI, I might reorganize the display to place related information in close proximity; i.e., the altitude, and VVI setting on the right, mach number and airspeed on the left. I would also place the bank indicator close to a heading display.

APPENDIX F

STATISTICAL PROCEDURES USED IN DATA ANALYSES

Amplitude distributions (Reference F1) of the time-history recordings of each parameter were constructed to evaluate the relative effects of the experimental conditions. Summary statistics descriptive of the error amplitude distribution of a sample of tracking performance were computed using the following formulae:

AE (Average error) =

$$\frac{1}{T}\int_0^T e\ (t)\ dt$$

AAE (Average absolute error) =

$$\frac{1}{T}\int_0^T |e\ (t)|\ dt$$

RMS (Root-mean-square error) =

$$\sqrt{\frac{1}{T}\int_0^T e^2\ (t)\ dt}$$

SD (Standard deviation) =

$$\sqrt{(RMS)^2 - (AE)^2}$$

where T is the time over which the parameter was integrated, e is the amplitude of the parameter at time t, and dt is the sampling interval. The AE is a numerical index of the central tendency of the amplitude distribution, while the SD reflects the variability or dispersion of the measures around this central tendency. RMS error is also an index of performance variability, but relative to the null point rather than the AE. AAE is the mean of the amplitude distribution replotted with all error amplitudes positive and is indicative of the variability when interpreted in conjunction with the other performance indices.

These summary statistics (AE, AAE, RMS, SD) were computed on the flight parameters ground speed, altitude, and flight director deviation from null for the time period specified by the event and for the immediate fifteen seconds prior to the event. Summary statistics for the fifteen second pre-event time for each parameter were subtracted from the corresponding values computed for the event in order to measure only the effect of the keyboard operations on the pilot's performance. An example calculation can be illustrated as follows:

Altitude AAE Event Time	−	Altitude AAE Pre-event Time (15 sec.)	=	Delta Altitude AAE Summary Statistic Used in Statistical Analysis

Keyboard task performance was evaluated by measuring the time required for the event and the number of switch hits. Since the number of required switch hits was not the same for the communication changes and navigation updates, a Figure of Merit (FOM) was computed by dividing the actual number of switch hits by the number required to accomplish the keyboard operation without error. For example, 19 switch hits were required to complete a navigation update correctly. Suppose a pilot made an error on the fourth switch hit, cleared the entry, and then entered the entire update correctly. The pilot then actually made 24 switch hits including the clear button in order to successfully complete the update. The FOM in this case would be:

$$\frac{24}{19} \qquad \frac{\text{(Actual number of switch hits made)}}{\text{(Number of switch hits required to complete task without error)}} = 1.26$$

The communication change, on the other hand, required nine switch hits. Let's say the pilot selected three digits before realizing he made an error, cleared the entry, and then selected and entered the correct frequency. The FOM in this case would be:

$$\frac{13}{9} \qquad \frac{\text{(Switch hits made)}}{\text{(Switch hits required)}} = 1.44$$

An error free task would produce a FOM of 1.0 and as errors increased, the FOM increased.

Statistical analyses were conducted on the following dependent variables:

- delta altitude AAE
- delta altitude RMS
- delta ground speed AAE
- delta ground speed RMS
- delta bank AAE
- delta bank RMS
- keyboard operation time
- figure of merit

These variables were initially analyzed by the use of the Biomedical (BMD) Statistical Computer Program 12V (Reference F2) which performs multivariate analysis of variance or covariance for any hierarchical design with equal cell sizes. In those cases where the MANOVA revealed significant effects, stepwise discriminant function analyses by the use of the BMD07M program were conducted. In performing a multiple group discriminant analysis, this program computes a set of linear classification functions by choosing the independent variables in stepwise manner. The variable entered at each step is selected by one of four available criteria and a variable is deleted when its F-value becomes too low.

F1. Obermayer, R. W., and Muckler, F. A., "Performance Measurement in Flight Simulation Studies." NASA-CR-82, July, 1964.

F2. Dixon, W. J., Ed., "BMD Biomedical Computer Programs." University of California Press, California, 1974.

APPENDIX G

WORK ANALYSIS

An analysis was performed in order to provide additional information about the total effect of different keyboards as a function of all of the dependent variables. Although the dependent variable most sensitive to changes in the independent variables could be identified, there was no consistent pattern. The total differences caused by variation in the independent variable could be measured only by a combination of the measurements of the dependent variable. A single metric for task difficulty was desired. This task difficulty is defined as "work" for this analysis.

The authors realize that true work measurements would include physiological factors and mental stresses, and that true work could vary without changes in the parameters which were measured. For simplicity of discussion, the term "work" is used as a measure of task difficulty. Easy tasks require a small amount of work. Difficult tasks require more work. A necessary assumption for the following analysis is that the subjects were actively involved in the task. Observations by the experimenters and discussions with the subjects after the experiment confirmed this assumption.

It was hypothesized that total work (or task difficulty) was a combination of work for the flying task, plus work for the keyboard task.

$$W = W_f + W_k \tag{G1}$$

As mentioned in Paragraph III-4.4, it was assumed that the realism of the simulation and the difficulty of the flying task would establish a work demand sufficiently difficult that perfect performance of the flying task was not possible and imposition of a keyboard task would result in a further degradation of flying task performance parameters. Variations in keyboard task difficulty would also be reflected in the keyboard task parameters; errors and time to correct completion. The results obtained through testing have verified these assumptions. The difficulty of the flying task at any given moment was reflected not only in the average error from each performance parameter but also in the variation of this error. With no keyboard task, this work level would be expected to remain essentially constant. When increased attention was given to the keyboard task, the average errors in the flying task performance parameters increased and the variations in the errors became greater.

RMS of the error is sensitive to changes in either the magnitude of the error or the variations in the error, or both. For this reason, RMS was selected as the appropriate statistic to indicate changes in the workload reflected in the performance of the three-dimensional tracking task. A linear combination of ground speed, altitude, and flight director bank error RMS was used to measure the work associated with the three flying task performance parameters. Since these errors were measured twenty times a second, they constitute error rates or errors per 0.05 second.

Flying an airplane is a continuous task. Work continues at a more or less constant rate and the total amount of work increases with time. Thus, the linear combination of parameters involves a multiplication of error rate by time in order to get the cumulative (or total) work measured by flying task performance parameters.

$$W_f = b_1 At + b_2 Vt + b_3 Bt \qquad \text{(G2)}$$

Where b's are the weighting coefficients, A is altitude RMS, V is velocity (GS) RMS, and B is flight director (bank) RMS, W_f is work on the flying task, and t is the time interval during which work was done.

The weighting coefficients can be expected to vary with differences in flight control systems. For this experiment, control laws were not varied and the coefficient remained constant. Indications of keyboard task difficulty were obtained by measuring the time required to complete the task and computing the Figure of Merit (errors made during the task). Difficult (high workload) tasks would be expected to take more time and/or produce more errors.

$$W_k = b_4 t + b_5 F \qquad \text{(G3)}$$

Where b's are weighting coefficients, t is time, F is Figure of Merit, and W is work on the keyboard task.

When Equations G2 and G3 are substituted into Equation G1, the result is:

$$W = b_1 At + b_2 Vt + b_3 Bt + b_4 t + b_5 F \quad (G4)$$

The five parameters in Equation G4 are indicated in Table 1. Each pilot was assigned the same original tasks. If each pilot completed the keyboard tasks without error, the work (as measured by performance indices) accomplished by each pilot would be the same. However, since the pilots were required to complete the task correctly, errors on the keyboard task resulted in a requirement to do additional work to correct the performance. This additional work is reflected in more switch hits and is included in the Figure of Merit parameter. Recall that the Figure of Merit is the number of switch hits used for the task divided by the minimum number of switch hits that should be needed to complete the task. When the parametric terms in the work equation are divided by the Figure of Merit, the work term no longer represents the total work done by a pilot but the work done "per switch hit." This is a form of normalization that allows comparison of work despite the fact that the switch hits (and hence, total work) vary with the task because of task differences or because of operator errors. When both sides of Equation G4 are divided by F and the constant b_5 is combined with the work term so that $W_o = \frac{W}{F} - b_5$, W_o

represents the work required to fly the simulator and actuate a switch, and constitutes a standard task. Then

$$W_o = b_1 \frac{At}{F} + b_2 \frac{Vt}{F} + b_3 \frac{Bt}{F} + b_4 \frac{t}{F} \quad (G5)$$

It should be apparent that the W_o for any subject is the same as W_o for any other subject. This equality will remain valid despite the use of various strategies by the subjects. That is, given a standard task (W_o), its work value remains constant regardless of which parameter receives the greatest share of operator attention. This conclusion is true if and only if the flying task is sufficiently difficult that it requires the full attention of the operator. As was discussed above, the condition was met in this experiment.

In Equation G5, the values of the four weighting coefficients (b_n) are unknown, but there are nine equations of the same form as G5; (one for each pilot based on his average performance during normal tasks). This constitutes an over specified set of equations.

A standard program (BMD02R) was used to obtain a solution from the over specified set of equations, based upon performances of the nine subject pilots on normal communication and navigation tasks. To obtain the weighting coefficients, stepwise regressions of the dependent variables were performed, using each variable in turn as the initial criterion, and the others as predictors. The value of W_0 was arbitrarily set at 100. Of the various linear solutions obtained, the following best fit equation was selected:

$$100 = 2.25150 \frac{t}{F} + 0.00196 \frac{At}{F} + 0.03758 \frac{Vt}{F} + 0.25079 \frac{Bt}{F} \qquad \text{(G6)}$$

It was selected because all coefficients of factors contributing to work are positive, reflecting the fact that increases in errors and time are indicative of increased work. Note that by setting the constant at 100 for this "standard" work task, solutions to the equation based upon other tasks will be in terms of percentage of the standard task. Thus, the equation establishes a metric for task difficulty, based upon flying task errors, keyboard task errors, and time to accomplish the keyboard task. An internal check of the equation reveals that an altitude error of 100 feet is equivalent to a velocity error of five knots. Flying experience establishes that holding velocity within five knots is about the same order of difficulty as holding altitude within 100 feet. It should be noted that Equation G5 is sufficiently general to be used for evaluation of keyboard task performance for any aircraft. Equation G6 has weighting coefficients that are specific for this simulation. Because the coefficients will vary with changes in the flight control systems, it is deemed inappropriate to use this method for comparing flight control systems.

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